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**SEISMIC QUALIFICATION OF OH-180
PROGRAMMABLE CONTROLLER PANELS FOR
DARLINGTON NGS**

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ABSTRACT

This report documents the seismic qualification analysis of OH-180 Programmable Controller panels installed at the Darlington Nuclear Generating Station. The seismic qualification analysis used a combination of dynamic shaker table tests, experimental modal tests and finite element analysis. Each panel is designed to hold up to ten OH-180 programmable controllers. The panels are installed singly or in lineups of two, three, four or six. Single panels were qualified by test, using the Ontario Hydro Mechanical Research Department tri-axial shaker table. Experimental modal tests and finite element models were used to extend the analysis to panels installed in groups (lineups). The qualification analysis shows that the equipment should survive a design basis earthquake (DBE) for the Darlington NGS site. Secondary response spectrum curves, describing the response at points on the panels where equipment is mounted, have been generated. These are the required response spectra (RRS) for any future testing of OH-180 instrument and electrical components.

job	file	date	report no.
740621-228-462	825.92	October 31, 1986	86-277-K



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EXECUTIVE SUMMARY

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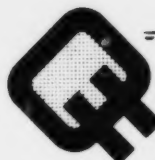
Some of the OH-180 Programmable Controller panels installed at the Darlington Nuclear Generating Station require seismic qualification. Qualification is demonstrated and documented in this report. This was accomplished through a combination of test and analysis, as outlined in a "Qualification Plan" appended to this report as Appendix "A". Panels installed singly and in groups of two, three, four and six are analyzed. Single panels were tested on a tri-axial shaker table. Modal tests and finite element analyses were used to extend the qualification to panels installed in lineups. The required response spectra for seismic qualification of individual electrical components are provided.



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TABLE OF CONTENTS

	<u>Page</u>
1.0 INTRODUCTION	1
1.1 Equipment Description	1
2.0 QUALIFICATION METHODOLOGY	2
2.1 Acceptance Criteria	2
2.2 Response Spectra Used in Analysis	3
3.0 QUALIFICATION ANALYSIS	3
3.1 Test Specimens	3
3.2 Shaker Table Tests	4
3.3 Description of Finite Element Models	4
3.4 Modal Tests	5
3.5 Eigenvalue Analysis and Model Verification	5
3.6 Response Spectrum Analysis	6
3.7 Transient Analysis	6
4.0 SUMMARY AND CONCLUSIONS	7
5.0 RECOMMENDATION	7
6.0 ACKNOWLEDGMENTS	8
REFERENCES	9
TABLE	10
FIGURES	11
APPENDIX A	62
DISTRIBUTION	last page



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To Mr. M.A. Machacek
Manager of Engineering
Darlington Engineering Department

**SEISMIC QUALIFICATION OF OH-180 PROGRAMMABLE
CONTROLLER PANELS FOR DARLINGTON NGS**

1.0 INTRODUCTION

This report presents the results of tests and analyses which demonstrate the seismic qualification of a number of OH-180 Programmable Controller panels installed at the Darlington NGS. These panels consist of electrical components which provide essential services to safety related systems. The qualification analysis used a combination of dynamic shaker table tests, experimental modal tests and finite element analyses. The detailed approach and procedures carried out are documented in the Qualification Plan issued for these panels which is provided in Appendix A. The qualification methodology and acceptance criteria are summarized in this report for convenience.

In addition, this report provides secondary response spectra curves to be used for any future qualification tests on individual OH-180 electrical components.

1.1 Equipment Description

This report deals with the "aseismic" type of OH-180 panels (2032 mm high) and covers the following panels:

Reactor auxiliary bay, secondary control area, Room 252

- PL2395 through PL2400
- PL2870 through PL2875
- PL3495 through PL3498

Room SM-105

- PL4157, PL4158
- PL4172, PL4173
- PL4190 through PL4192
- PL4831, PL4132
- PL4843, PL4844
- PL4857 through PL4859
- PL5481, PL5482
- PL5493, PL5494

Emergency Power Supply Building

- PL6351
- PL6642

2.0 QUALIFICATION METHODOLOGY

Single panels were tested on a tri-axial shaker table which simulated design basis earthquake (DBE) motion for the location of these panels at the Darlington NGS. Qualification for longer line-up arrangements used a combination of test and theoretical analysis. The basic strategy was to demonstrate that the maximum anticipated level of response of the line-ups due to a DBE level earthquake is less than the response experienced by the test sample during shaker table tests.

The finite element models used in the analysis were verified through modal tests of single panel and two panel line-up configurations.

2.1 Acceptance Criteria

The panels covered by this report are required to remain functional during and after a Design Basis Earthquake (DBE), as defined by the response spectra specified in Section 2.2 below. For the purpose of the qualification tests, we regard this as being equivalent to demonstrating that the uppermost controller and communications modules in each test panel are capable of running diagnostic self-test programs continuously during and after the shaker tests. (The rationale for choosing the uppermost units is explained in the Qualification Plan.) In addition, at least one of the cooling fans located at the bottom of the cabinet must remain functional after the shaking. After the seismic shaker test, the panel is inspected for visible structural damage to the frame or electrical equipment. The panel is considered qualified if no damage, which would lead to collapse or significant distortion, is found.

For the case of the OH-180 Controllers, the self-test program referred to in the previous paragraph is an overall functional self-test program known as "FUNC". Document PC-TP-FUNC in Appendix D of reference/5.0/ describes the FUNC self-test in detail, including the scope, procedure and pass/fail criteria. For the case of communications modules (CM), the self-test program consists of a full 2-station communication loop comprising two OH-180s and two CMs, running operating ladder diagrams complete with the normal run-time fault and error detection. In this test loop, the ladder diagrams for each of the two host OH-180 PCs were designed to set and reset one communication output point at a regular rate. Each output is used as a communication input by the other OH-180 PC and the status transferred to a particular output point on that OH-180. This results in a regular flashing pattern on the output indicator of each OH-180 PC, provided that both OH-180s and CM continue to operate properly. The presence of the flashing pattern can thus be used as a pass/fail criterion. In addition, while processing the ladder diagrams, the CMs also perform a number of self-tests for fault and errors, as part of the normal functions of their executive software/6/. Any errors detected by the CMs would be indicated by the lighting of the "WIRING FLT" error indicator on the front panel of the associated host PC. In summary, the CM self-test is considered to have passed if the regular flashing of the output indicators of the associated OH-180 PCs continue for the entire duration of the test with no stoppage, interruption, "glitch" or modification, and if no "WIRING FLT" errors are indicated.

Panels installed in line-ups will be considered qualified if the peak seismic acceleration computed for the line-up due to RRS loading is less than the peak acceleration experienced by the single panels during shaker table tests.

Verification of finite element models used for seismic qualification of line-up assemblies is confirmed if at least the first two vibration modes found by analysis match the vibration modes found by experimental modal tests for the single and two panel line-up configurations. In addition, for each vibration mode of comparison, the natural frequency predicted by analysis must be within 10% of frequencies found by modal tests.

2.2 Response Spectra Used in Analysis

The Required Response Spectra (RRS) curves for locations where the safety related OH-180 programmable controller panels are installed are provided in the qualification plan. Response spectra corresponding to a damping of 3% of critical were used for response spectrum analysis computer runs.

The RRS curves are used to develop upper bound response spectra for the horizontal and vertical directions. The horizontal RRS curve used for finite element analysis is provided in Figure 7. The vertical RRS curve is provided in Figure 8. The TRS curves are obtained from the single panel shaker tests.

3.0 QUALIFICATION TESTING AND ANALYSIS

3.1 Test Specimens

The following types of equipment were tested:

(i) OH 180 Programmable Controller Equipment Cabinets

- OH 180 PC, 5 high top entry, S/C 817D024.

(ii) OH 180 Programmable Controller

- Crates, c/w mother board, S/C 817D6394.
- Power supply boards, S/C 817C7101.
- CPU boards PCD2, S/C 817C7115.
- Input Boards PCD4, S/C 817C7136.
- Output Boards PCD5, S/C 817C7143.
- EPROM Boards PCD3, S/C 817C7122.
- System Expansion Jumper Cables, S/C 817C7192
- Cable, S/C 718C8562.

(iii) OH 180 Communications Modules

- Power Supply S/C 817H1025
- F.O. Interface S/C 817H1011
- Processor S/C 817H1004
- Sheet Metal Package S/C 817G5120

All equipment, except for the communications modules, were regular production units selected at random from equipment on hand at Darlington.

The communications modules were pre-production prototypes obtained from the Electrical Research laboratory. These units were however, identical in specification to the production version.

The test panels were fitted with a full set of cables to duplicate the weight distribution of field mounted panels.

3.2 Shaker Table Tests

Two single panel configurations were mounted on the Ontario Hydro Mechanical Research Department tri-axial shaker table: a panel fully loaded with ten controllers and a panel with eight controllers plus communications modules in the top space. As was described in the test plan, the testing of these two configurations will cover all cases of partially loaded panels. A photograph of a single panel with ten controllers mounted on the shaker table is provided in Figure 15. Most of the connecting cables, which enter through the top of these cabinets, were suspended from an overhead crane during the shaker and modal tests so that the mechanical loads imposed on the panels by these cables were simulated as closely as possible. A pair of cables was connected to test equipment needed to run the diagnostic self-test programs.

The panels were subjected to approximately 30 seconds of table motion enveloping the RRS curves, specified in Section 2.2, over the 1 to 33 Hz frequency range.

The experimental test spectra are provided in Figures 1 to 6. These figures compare the test response spectrum (TRS) for the table motion with the RRS for each direction. All TRS curves envelope RRS curves over the 1 to 33 Hz frequency range.

The self-test programs, as described in Section 2.1, ran successfully on the monitored programmable controller and communications module during and after the shaker tests. Both cooling fan units were tested after the shaker tests and found to be operational. During the shaker table tests, the response near the top of each single panel configuration was measured and recorded. They are provided in Figures 9 to 14.

Post test inspection revealed that five of the ten bolts supporting the communications module support plate had failed in shear. These bolts attach the support plate to flanges welded to the enclosure. The support plate was adequately supported by the remaining five bolts. A schematic sketch showing the location where the bolts were sheared is provided in Figure 16. The bolts supporting the communications modules onto the CM support plate were all intact.

In addition, inspection of the frame revealed hairline cracks at several locations on the periphery of the steel enclosure. A sketch showing the locations of these cracks is provided in Figure 17.

3.3 Description of Finite Element Models

A general description of the finite element analysis is provided in the qualification plan, Appendix A.

Three dimensional finite element models of single panel, two, three, four and six panel assemblies were developed for analysis. The models were made using beam, plate and concentrated mass elements. Dimensions and section properties were taken from Reference 4. Schematic sketches of the models are provided in Figures 18 to 22.

Concentrated mass elements, representing the mass of internal electrical components, were lumped along the frame of the enclosures.

3.4 Modal Tests

Structural dynamic tests were carried out on the single panel and two panel line-up configurations. The sample panels were bolted to a four inch thick steel slab which is bolted to a heavily reinforced concrete floor. This arrangement was intended to duplicate the rigid mounting of the panels in the generating station. The two panels mounted in line-up arrangement were connected side-by-side with two pieces of steel strip running along the front and back top edges of the cabinets. The purpose of the steel strips was to prevent adjacent panels from impacting during an earthquake. The strips were bolted to the cabinets using lifting lug holes located on the top of each cabinet. Photographs of the two panel line-up and a close-up of the connection is provided in Figures 23 and 24.

The tests determined natural frequencies and major vibration modes of the two arrangements described earlier. The response was measured by accelerometers mounted at points indicated in Figures 25 and 26. The qualification plan provides a more detailed description of the testing procedure. The test results were used to verify the finite element models. The results are presented in the following section.

3.5 Eigenvalue Analysis and Model Verification

The eigenvalue analysis of a single panel showed four natural frequencies below 33 Hz. The first mode is dominated by side to side motions (in the x-direction) at a frequency of 12.2 Hz. The second mode is dominated by front to back displacements (in the z direction) at a frequency of 16.1 Hz. Mode shapes at these natural frequencies are provided in Figures 27 and 28.

The experimental modal tests of the single panel found natural frequencies at 13.1 Hz for the first mode (dominated by side to side displacements) and 16.0 Hz for the second mode (dominated by front to back displacements). Mode shapes of these natural frequencies are provided in Figures 29 and 30.

The eigenvalue analysis of the two panel line-up configuration found eight natural frequencies below 33 Hz. The first mode occurs at a natural frequency of 12.5 Hz (dominated side to side displacements). The second mode occurs at a natural frequency of 15.9 Hz (dominated by front to back displacements). Mode shapes of these natural frequencies are provided in Figures 31 and 32.

The modal tests of the two panel line-up found natural frequencies at 12.8 Hz for the first mode (dominated by side to side displacements) and 14.5 Hz for the second mode (dominated by front to back displacements). Mode shapes of these natural frequencies are provided in Figures 33 and 34.

A comparison of analytical to experimentally measured natural frequencies and mode shapes indicates that the first 2 vibration modes are within the acceptance criteria of Section 2.1. The finite element models are a good representation of OH-180 programmable controller panels.

The mode shapes of the first two natural frequencies found by finite element models of panels installed in groups of three, four and six are provided in Figures 35 to 40.

3.6 Response Spectrum Analysis

Response spectrum analyses of the finite element models described in section 3.2 were carried out. A structural damping ratio of 3 per cent of critical was assumed, as recommended in Table 3 of Reference /3/ (item #4). The required calculations were all carried out by the computer program, MSC/NASTRAN.

The acceleration measured near the top, where the enclosure will experience maximum acceleration, of each single panel configuration test on the shaker table was compared to the maximum seismic acceleration response of each line-up assembly, subjected to RRS loading. The comparison is summarized in Table 1.

In each case, the acceleration response measured during shaker tests is greater than the maximum acceleration response on all line-up configurations modeled. The shaker table tests measured peak accelerations of 5.3 g in the transverse direction and 3.7 g in the vertical direction.

3.7 Transient Analysis

Transient analysis of the single, two, four and six panel assemblies was carried out to produce secondary response spectra that define seismic loading for electrical components mounted in the OH-180 programmable controller panels.

Secondary response spectra for sample points on the panel configurations analyzed were generated. Sketches of the finite element models presented in section 3.2 designate locations where secondary spectra are generated. Spectra were generated using finite element models of panels installed singly and in groups of two, four and six. These models were subjected to time histories that are spectrum compatible to the RRS.

A thorough survey of response spectra generated for the single panel and multi-panel configurations was carried out. The response spectra loading experienced near the top of the panel during shaker table tests are compared to secondary response spectra obtained from finite element models at approximately the same location. They are presented in Figures 41 to 52. The spectra correspond to a critical damping ratio of 1%.

The secondary response spectra generated in the vertical (y-axis) and front to back (z-axis) directions show that the response of the line-up configurations is less than the response experienced by single panels during seismic shaker table tests.

The response spectra loading experienced by the single panels during shaker table tests in the side to side (x-axis) direction does not entirely envelope the computed secondary response spectra in the same direction for line-up assemblies.

Accelerations in the panel during the shaker test were strongest in the 4 to 6 Hz range, while the analysis predicts peak response between 12 and 16 Hz, near the natural frequency of the

configuration. We believe that this occurs because of a rocking mode of vibration of the shaker table at about 5 Hz. The overall intensity of shaking experienced during the shaker tests was approximately three times higher than the maximum acceleration predicted for the in-plant installation. Because of this large margin, we believe that the equipment which passed the shaker tests is extremely unlikely to be put out of commission by a DBE level earthquake, even if the predominant frequencies of the excitation are different.

4.0 SUMMARY AND CONCLUSIONS

Results from the shaker table tests show that the single panels can withstand a DBE earthquake without suffering damage that would lead to collapse or significant distortion. Minor structural failures occurred but did not interfere with the function of the controllers and communications module. The self-test programs, as described in Section 2.1, ran continuously and successfully during and after the shaker table tests. The test response spectrum curves measured on the shaker table envelope the required floor response spectrum curves for this equipment at the Darlington site.

Finite element model of a single panel was developed and combined to create line-up configurations. Experimental modal tests were used to verify finite element models of panels installed in groups to extend the qualification analysis to line-up configurations.

A response spectrum analysis of finite element models of panels installed singly and in groups of two, three, four and six was carried out. The response of the single panel model during shaker table tests was compared to the response of the multi-panel configurations. The maximum seismic response on the tested single panel was greater than the response that would be experienced by panels installed in groups, subjected to a DBE level earthquake.

This analysis tested fully loaded OH-180 programmable controller panels. A panel with the identical frame of those analyzed and which contain less controllers will have the same stiffness but a smaller load distribution. Therefore, this analysis covers the case of partially loaded panels.

Secondary response spectra for sample points on the panels were generated using finite element models. These curves could be used for shaker tests of individual electrical components.

A comparison of response spectra loading experienced near the top of sample panels during shaker tests to response spectra predicted by finite element models at approximately the same location revealed that the predominant frequencies of excitation are not in agreement. As a result, the loading experienced by sample panels during shaker tests does not envelope the computed response spectra loading in the side-to-side direction at all frequencies. The response of the line-up assemblies for the vertical and front-to-back directions is less than the response loading measured during shaker tests.

We conclude that the OH-180 Programmable Controller panels will withstand the DBE level earthquake for the Darlington Nuclear Generating Station site.

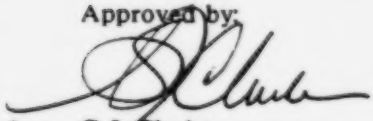
5.0 RECOMMENDATIONS

The failure of bolts holding the communications modules support plate was apparently due to shearing of the bolts heads as a result of distortion of the cabinet structure. Larger hole clearance, with a plain washer under the bolt head, should eliminate this problem.

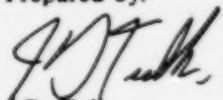
6.0 ACKNOWLEDGMENTS

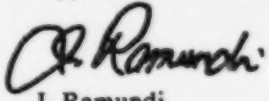
The shaker table tests were carried out with the assistance of Mr. G.D. Paulsen. Mr. P.A. Peruzzo was involved with the installation of the monitored programmable controller and communications module. The authors wish to thank them for their assistance.

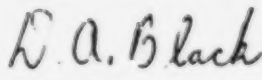
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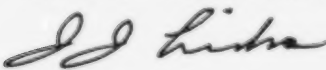

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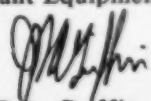
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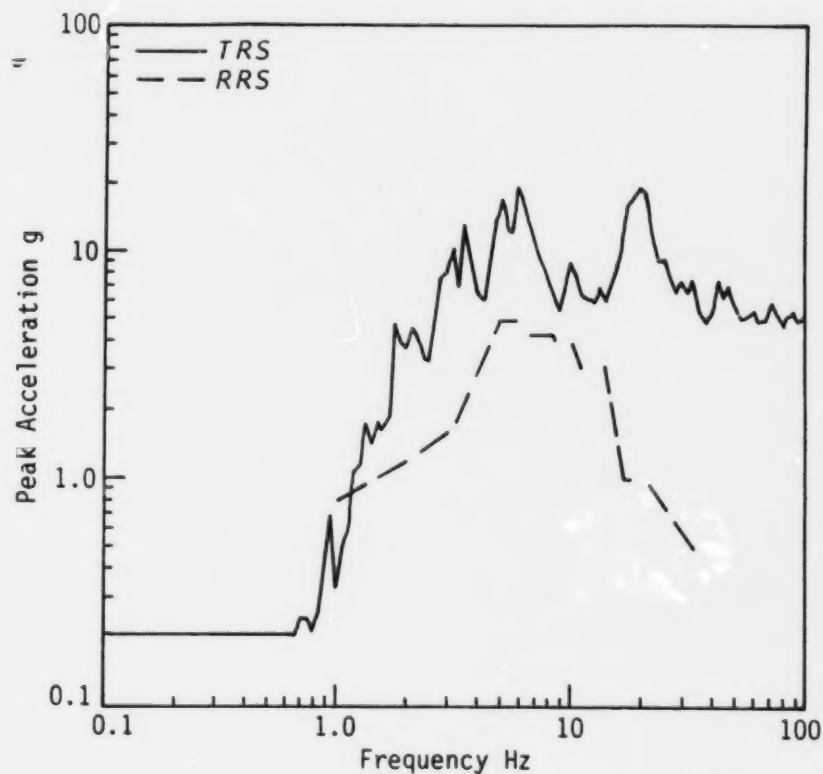
JR:lAg

REFERENCES

- 1.0 Ontario Hydro Specification STD5-X-50090-0002 "Seismic Qualification of Electrical Equipment and Components", Design and Construction Branch, Electrical Design Department, Issued November, 1979.
- 2.0 IEEE Std 344 (1975), "Recommended Practices for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations", Institutions of Electrical and Electronics Engineers, 1975.
- 3.0 Canadian Standards Association, CAN-N289.3-M81, "Design Procedures for Seismic Qualification of Candu Nuclear Power Plants", September 1981.
- 4.0 Ontario Hydro Drawing No FD 540072, Issue 2, "OH 180 Programmable Controller (EPS) Cabinet Weldment s/a 5 High Top Entry".
- 5.0 Griffin, J.D.A., "OH-180 Programmable Controller Manual", Ontario Hydro, Research Division Report No 84-284-H, October 29, 1984.
- 6.0 Whitmell, H.E., "OH-180 Communications Module Technical Manual", Ontario Hydro Research Division Report No 85-255-H, July 18, 1986.

TABLE 1
RESPONSE SPECTRUM ANALYSIS
COMPARISON OF MAXIMUM SEISMIC RESPONSES

MODEL	MAXIMUM DISPLACEMENT (Inches)			MAXIMUM ACCELERATION (g)		
	X-DIV	Y-DIV	Z-DIV	X-DIV	Y-DIV	Z-DIV
SINGLE PANEL	0.118	0.011	0.061	1.8	0.2	1.7
TWO PANEL LINE-UP	0.102	0.013	0.068	1.6	0.3	1.4
THREE PANEL LINE-UP	0.085	0.013	0.070	1.4	0.3	1.5
FOUR PANEL LINE-UP	0.071	0.012	0.067	1.2	0.3	1.5
SIX PANEL LINE-UP	0.066	0.012	0.068	1.2	0.3	1.6
SHAKER TABLE TESTS						
PANEL WITH 8 CONTROLLERS 1600mm FROM BASE	-	-	-	5.3	3.7	5.3
PANEL WITH 10 CONTROLLERS 1850mm FROM BASE	-	-	-	5.3	3.7	5.3



Test Item

OH 180 Cabinet c/w 8 Controllers, Tele-Radio, Model 701057.
Serial 018, S/C 817-D702

Particulars

May 27/86, Time 11:00, Temp(°C) 23, Humidity (%) 53, Press (kPa) 100.1,
Graph 5738

Specifications

Specs IEEE 344, Conditions #2, #3, #4 controllers operating

Analysis

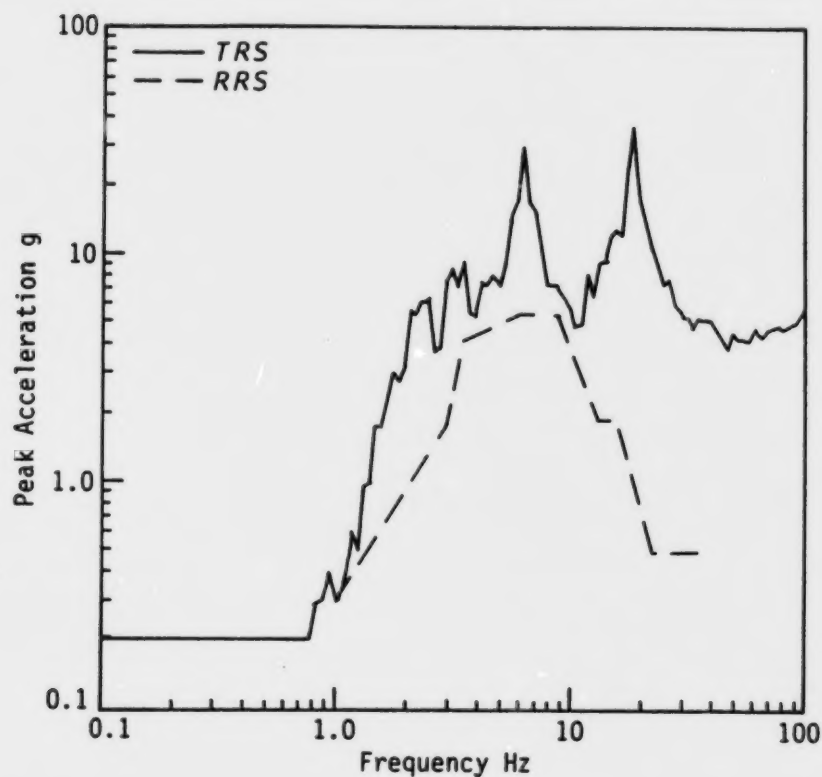
Type Maximax, Damping (%) 1, B.W. = 1/12 Octaves, Axis X,
Shaker tri-axial

Accelerometer

Endevco, Serial HP64, Range dB48, Location table, TT 0539, Channel 1

FIGURE 1

TEST RESPONSE SPECTRUM FOR OH-180 PANEL
WITH 8 CONTROLLERS (X-AXIS)



Test Item

OH 180 Cabinet c/w 8 Controllers, Tele-Radio, Model 701067,
Serial 018, S/C 817-D702

Particulars

May 27/86, Time 11:00, Temp (°C) 23, Humidity (%) 53, Press (kPa) 100.1,
Graph 5739

Specifications

Specs IEEE 344, Conditions #2,#3,#4 controllers operating

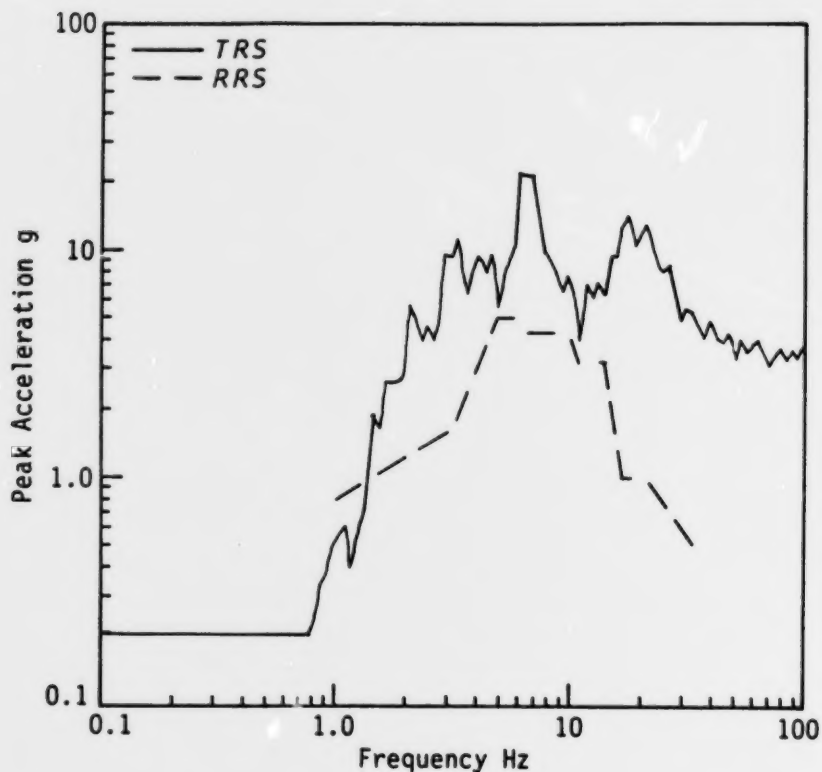
Analysis

Type Maximax, Damping (%) 1, B.W. = 1/12 Octaves, Axis Y,
Shaker tri-axial

Accelerometer

Endevco, Serial HG35H, Range dB48, Location table, TT 0539,
Channel 2

FIGURE 2
TEST RESPONSE SPECTRUM FOR OH-180 PANEL
WITH 8 CONTROLLERS (Y-AXIS)



Test Item

OH 180 Cabinet c/w 8 Controllers, Tele-Radio, Model 701067,
Serial 018, S/C 817-D702

Particulars

May 27/86, Time 11:00, Temp (°C) 23, Humidity (%) 53, Press (kPa) 100.1,
Graph 5740

Specifications

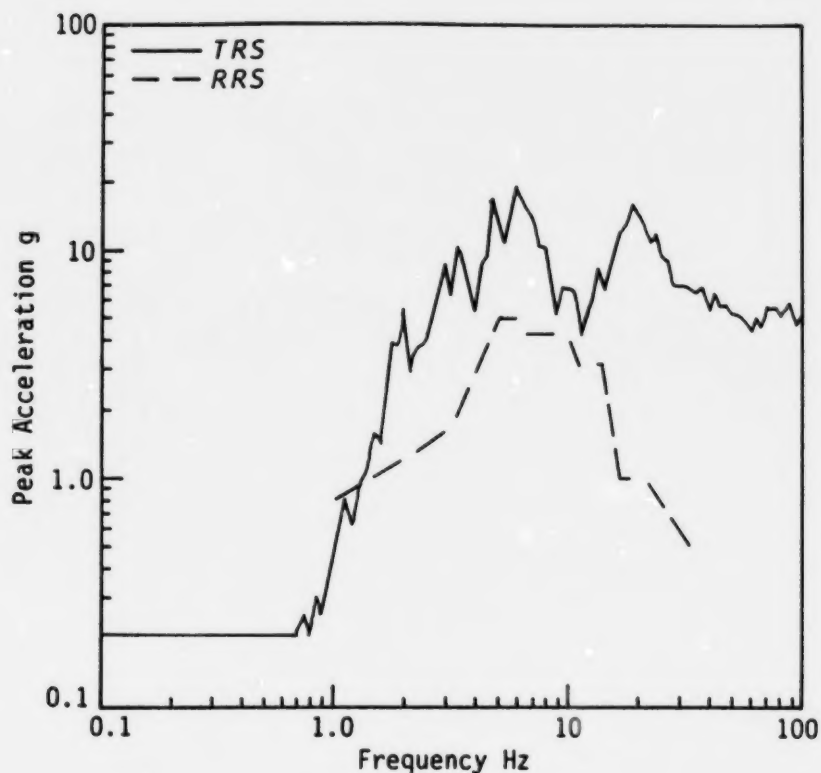
Specs IEEE 344, Conditions #2, #3, #4 controllers operating
analysis

Type Maximax, Damping (%) 1, B.W. = 1/12 Octaves, Axis Z,
Shaker tri-axial

Accelerometer

Endevco, Serial HN60H, Range dB48, Location table, TT 0539,
Channel 3

FIGURE 3
TEST RESPONSE SPECTRUM FOR OH-180 PANEL
WITH 8 CONTROLLERS (Z-AXIS)



Test Item

OH 180 Cabinet c/w 10 Controllers, Tele-Radio, Model 701067,
Serial 018, S/C 817-D702

Particulars

May 28/86, Time 1:00, Temp (°C) 23, Humidity (%) 53, Press (kPa) 100.1,
Graph 5744

Specifications

Specs IEEE 344, Conditions unit #2 operating in FUNC mode

Analysis

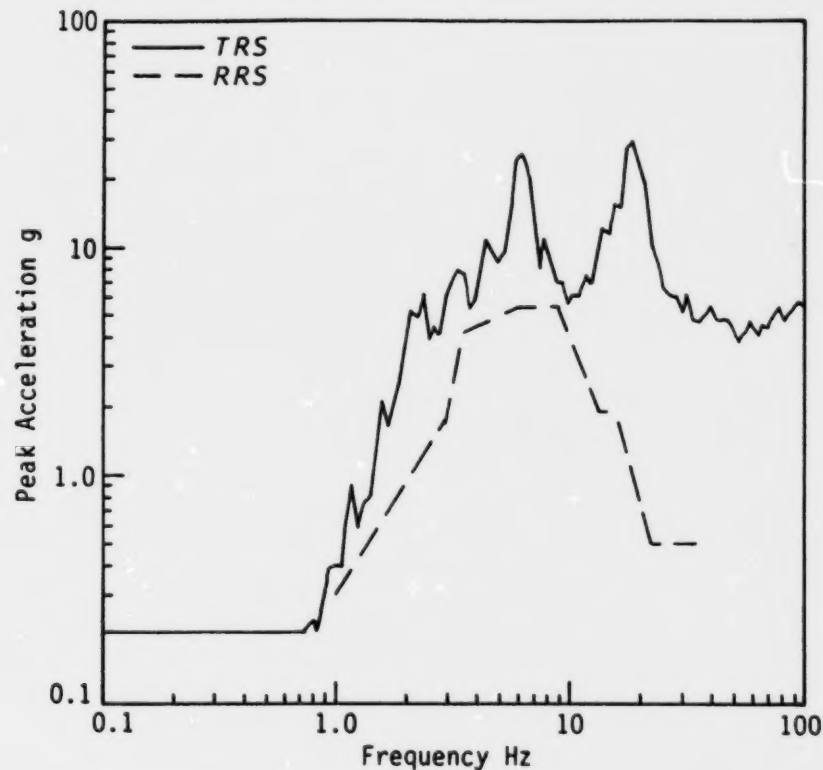
Type Maximax, Damping (%) 1, B.W. = 1/12 Octaves, Axis X,
Shaker tri-axial

Accelerometer

Endevco, Serial HP64, Range dB48, Location table, TT 0541,
Channel 1

FIGURE 4

TEST RESPONSE SPECTRUM FOR OH-180 PANEL
WITH 10 CONTROLLERS (X-AXIS)



Test Item

OH 180 Cabinet c/w 10 Controllers, Tele-Radio, Model 701067,
Serial 018, S/C 817-D702

Particulars

May 28/86, Time 1:00, Temp (°C) 23, Humidity (%) 53, Press (kPa) 100.1,
Graph 5745

Specifications

Specs IEEE 344, Conditions unit #2 operating in FUNC mode

Analysis

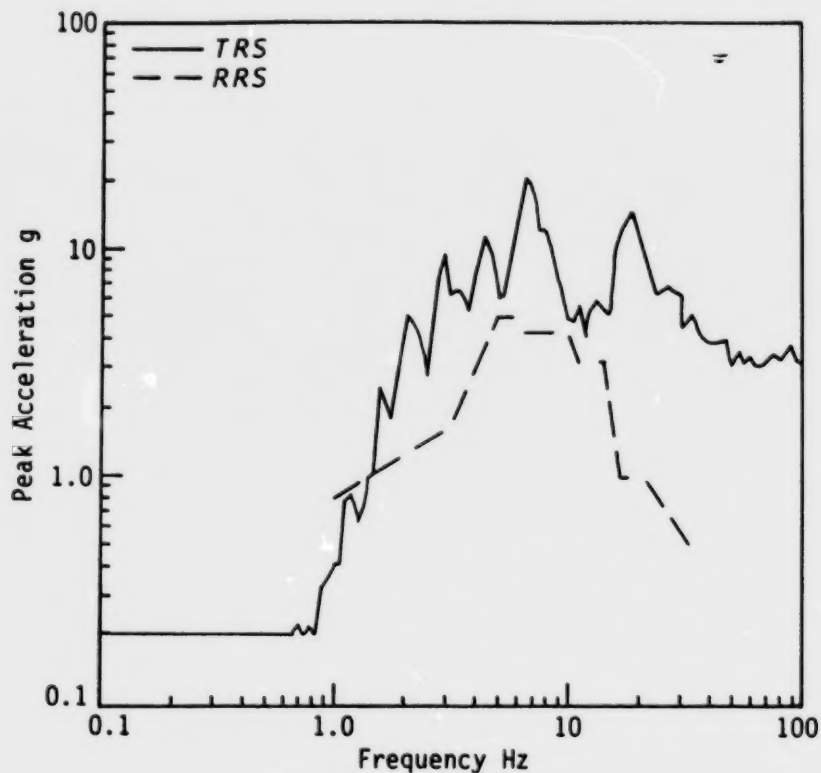
Type Maximax, Damping (%) 1, B.W. = 1/12 Octaves, Axis Y,
Shaker tri-axial

Accelerometer

Endevco, Serial HG35H, Range dB48, Location table, TT0541,
Channel 2

FIGURE 5

**TEST RESPONSE SPECTRUM FOR OH-180 PANEL
WITH 10 CONTROLLERS (Y-AXIS)**



Test Item

OH 180 Cabinet c/w 10 Controllers, Tele-Radio, Model 701067,
Serial 018, S/C 817-D702

Particulars

May 28/86, Time 1:00, Temp (°C) 23, Humidity (%) 53, Press (kPa) 100.1,
Graph 5746

Specifications

Specs IEEE 344, Conditions unit #2 operating in FUNC mode

Analysis

Type Maximax, Damping (%) 1, B.W. = 1/12 Octaves, Axis Z,
Shaker tri-axial

Accelerometer

Endevco, Serial HN60H, Range dB48, Location table, TT 0541,
Channel 3

FIGURE 6
TEST RESPONSE SPECTRUM FOR OH-180 PANEL
WITH 10 CONTROLLERS (Z-AXIS)

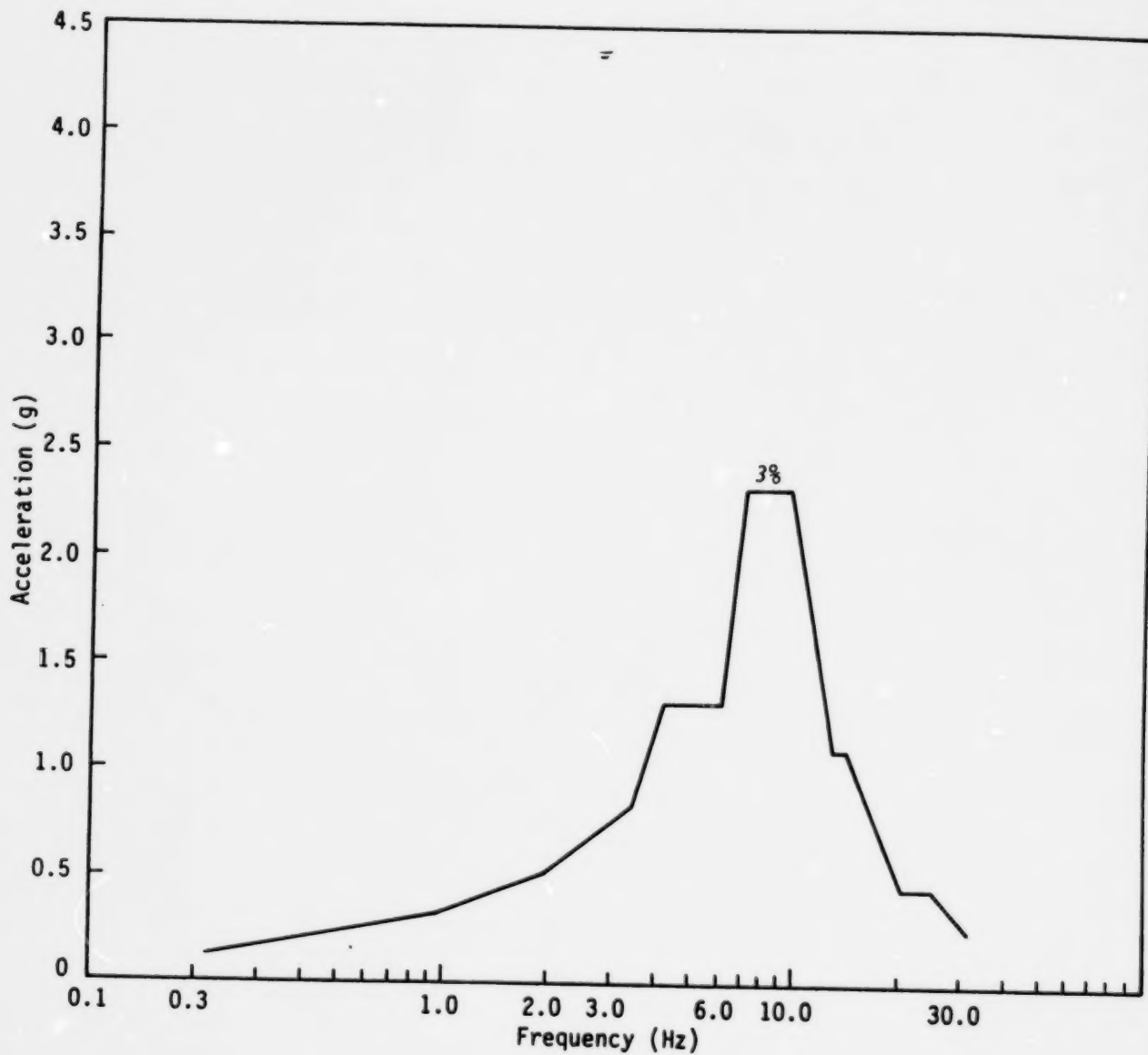


FIGURE 7
HORIZONTAL RESPONSE SPECTRUM
USED FOR FINITE ELEMENT ANALYSIS

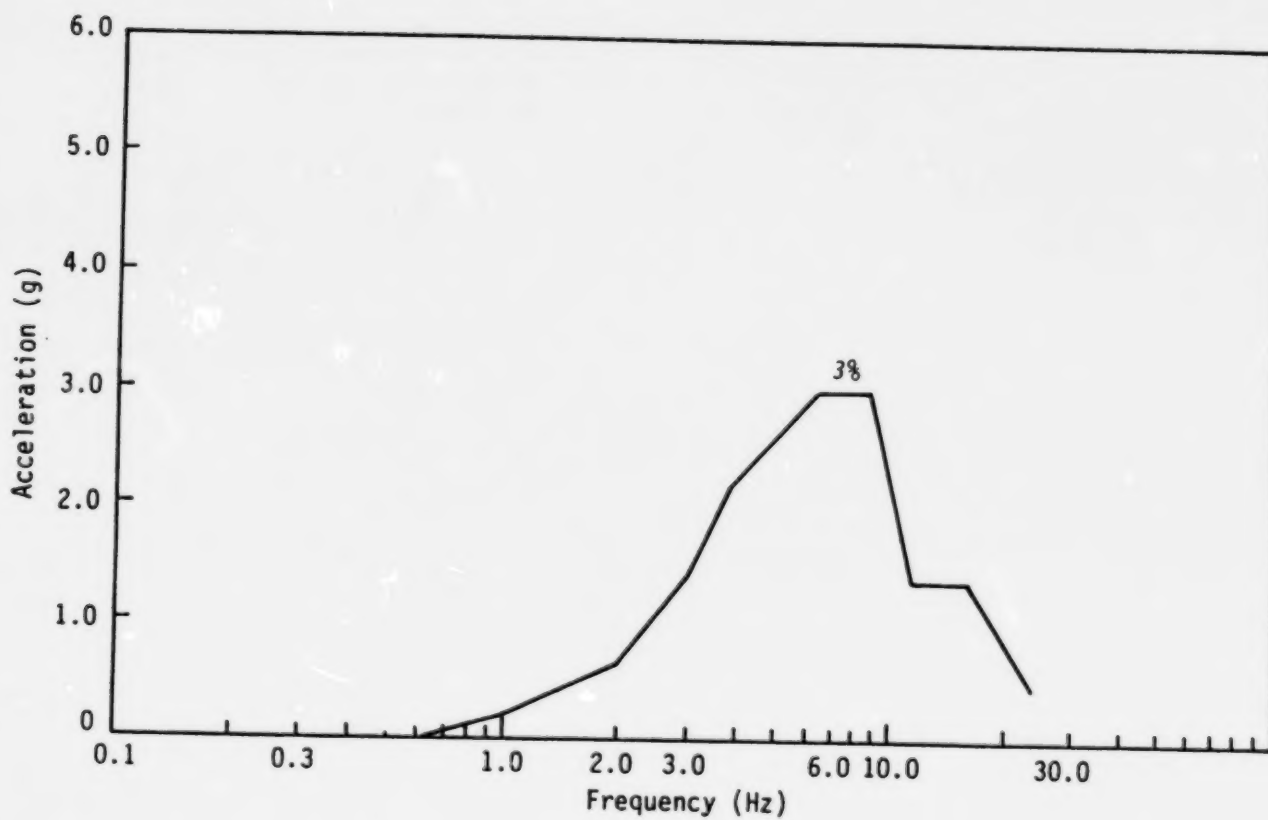
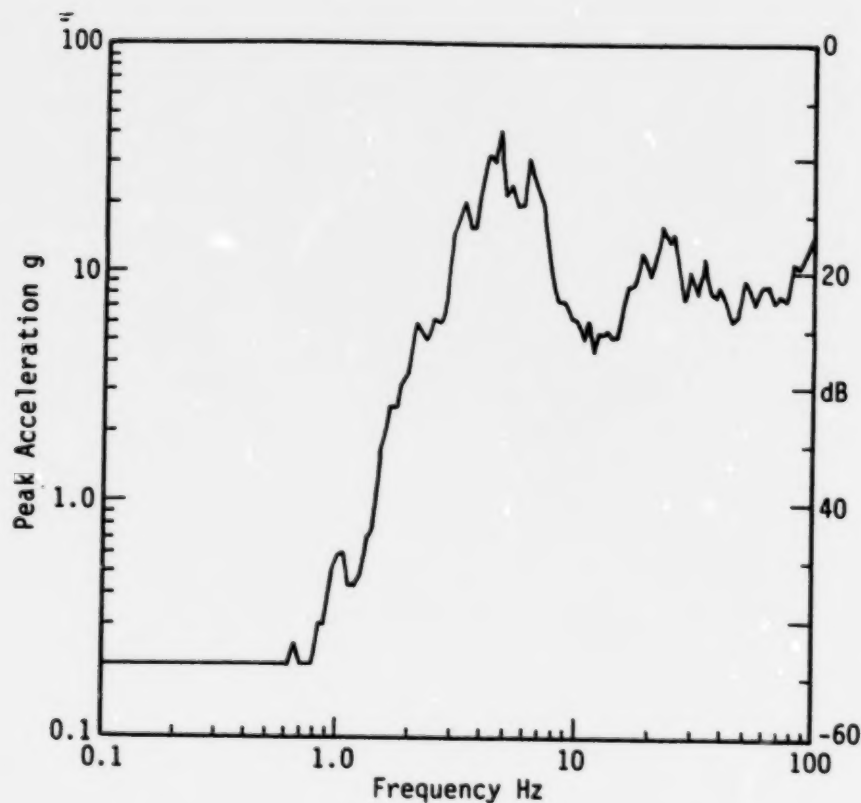


FIGURE 8
VERTICAL RESPONSE SPECTRUM
USED FOR FINITE ELEMENT ANALYSIS



Test Item

OH 180 Cabinet c/w 8 Controllers, Tele-Radio, Model 701067.
Serial 018, S/C 817-D702

Particulars

May 27/86, Time 11:00, Temp (°C) 23, Humidity (%) 53, Press(kPa) 100.1,
Graph 5741

Specifications

Specs IEEE 344, Conditions #2, #3, #4 Controllers Operating

Analysis

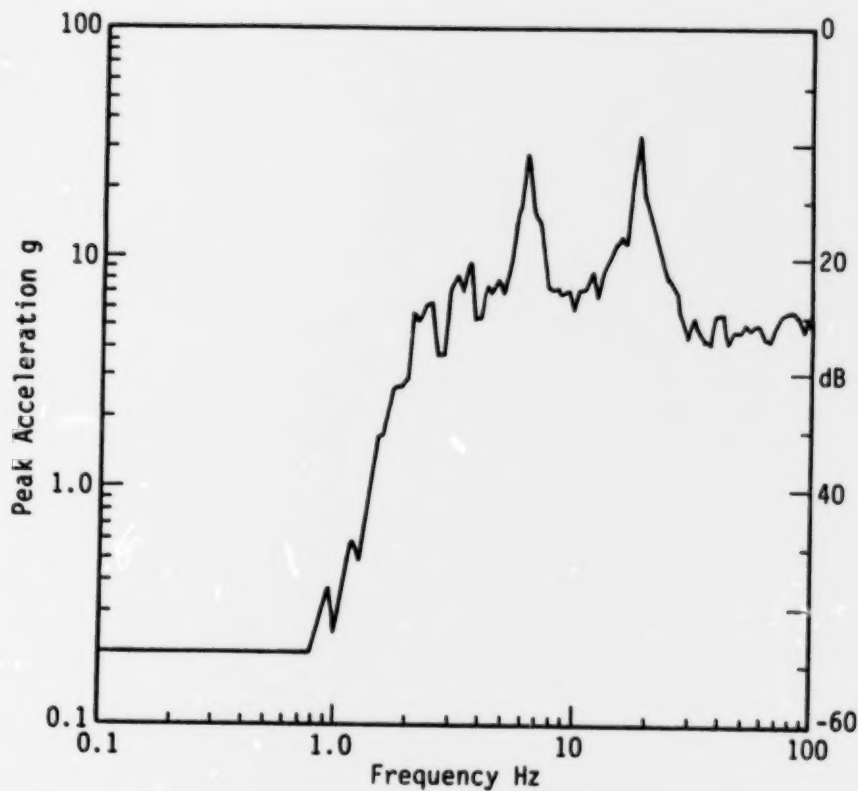
Type Maximax, Damping (%) 1, B.W. = 1/12 Octaves, Axis X,
Shaker Tri-Axial

Accelerometer

Bruel & Kjaer, Serial 1230061, Range dB48,
Location 1600mm from Base, TT 0539, Channel 4

FIGURE 9

TEST RESPONSE SPECTRUM 1600mm FROM BASE
OF PANEL WITH 8 CONTROLLERS (X-AXIS)



Test Item

*OH 180 Cabinet c/w 8 Controllers, Tele-Radio, Model 701067,
Serial 018, S/C 817-D702*

Particulars

*May 27/86, Time 11:00, Temp(°C) 23, Humidity(%) 53, Press(kPa)100.1,
Graph 5742*

Specifications

Specs IEEE 344, Conditions #2,#3,#4 Controllers Operating

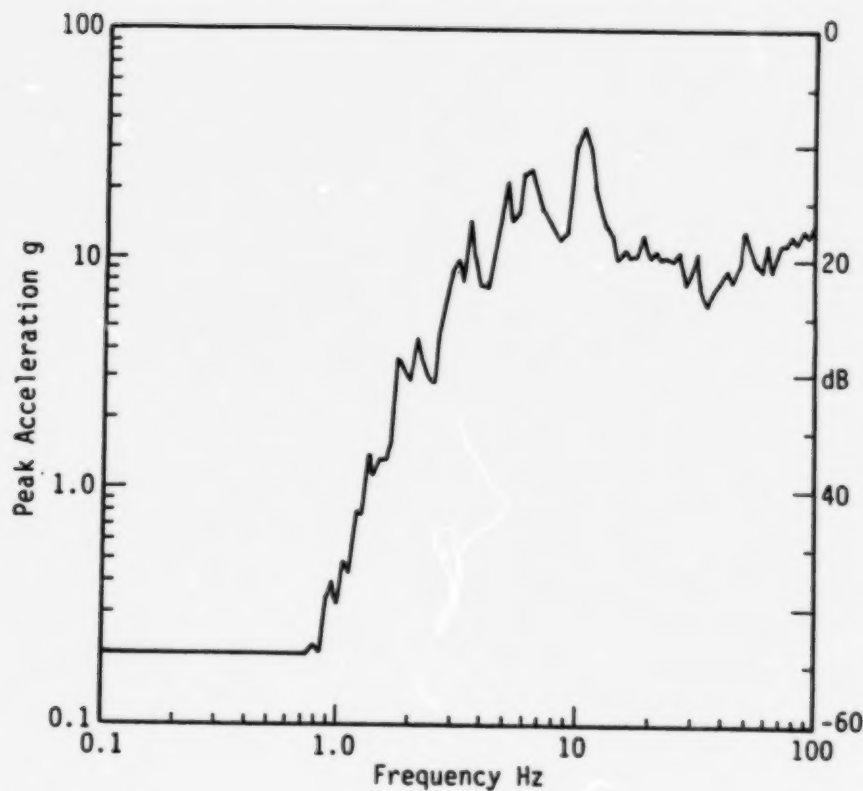
Analysis

*Type Maximax, Damping (%) 1, B.W. = 1/12 Octaves, Axis Y,
Shaker Tri-Axial*

Accelerometer

*Bruel & Kjaer, Serial 1230045, Range dB48,
Location 1600mm from Base, TT 0539, Channel 5*

FIGURE 10
TEST RESPONSE SPECTRUM 1600mm FROM BASE
OF PANEL WITH 8 CONTROLLERS (Y-AXIS)



Test Item

OH 180 Cabinet c/w 8 Controllers, Tele-Radio, Model 701067,
Serial 018, S/C 817-D702

Particulars

May 27/86, Time 11:00, Temp(°C) 23, Humidity(%) 53, Press(kPa) 100.1,
Graph 5743

Specifications

Specs IEEE 344, Conditions #2, #3, #4 Controllers Operating

Analysis

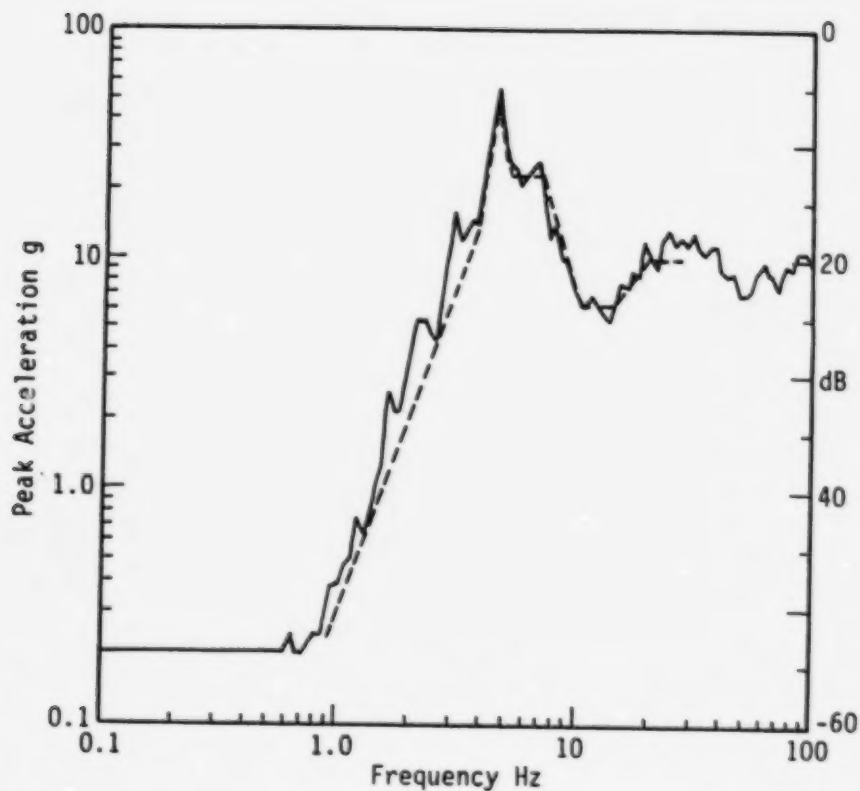
Type Maximax, Damping (%) 1, B.W. = 1/12 Octaves, Axis Z,
Shaker Tri-Axial

Accelerometer

Bruel & Kjaer, Serial 1230283, Range dB48,
Location 1600mm from Base, TT 0539, Channel 6

FIGURE 11

TEST RESPONSE SPECTRUM 1600mm FROM BASE
OF PANEL WITH 8 CONTROLLERS (Z-AXIS)



Test Item

*OH 180 Cabinet c/w 10 Controllers, Tele-Radio, Model 701067,
Serial 018, S/C 817-D702*

Particulars

*May 28/86, Time 1:00, Temp(°C) 23, Humidity(%) 53, Press(kPa)100.1,
Graph 5747*

Specifications

Specs IEEE 344, Conditions Unit #2 Operating in FUNC Mode

Analysis

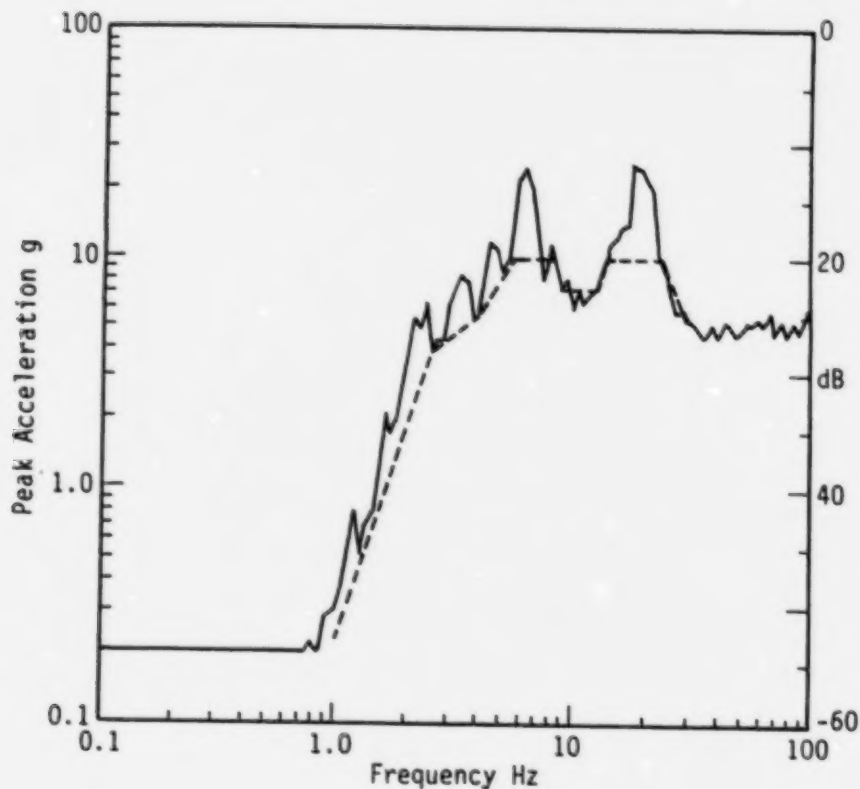
*Type Maximax, Damping (%)1, B.W. = 1/12 Octaves, Axis X,
Shaker Tri-Axial*

Accelerometer

*Bruel & Kjaer, Serial 1230061, Range dB48,
Location 1850mm from Base, TT 0541, Channel 4*

FIGURE 12

TEST RESPONSE SPECTRUM 1850mm FROM BASE
OF PANEL WITH 10 CONTROLLRS (X-AXIS)



Test Item

OH 180 Cabinet c/w 10 Controllers, Tele-Radio, Model 701067,
Serial 018, S/C 817-D702

Particulars

May 28/86, Time 1:00, Temp(°C) 23, Humidity(%) 53, Press(kPa) 100.1,
Graph 5748

Specifications

Specs IEEE 344, Conditions Unit #2 Operating in FUNC Mode

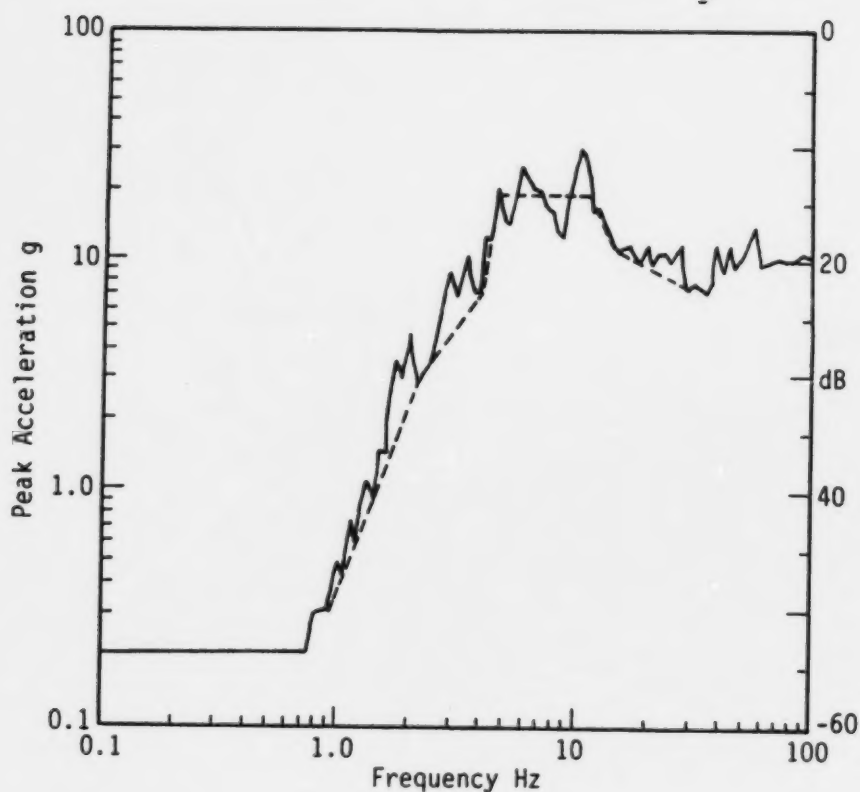
Analysis

Type Maximax, Damping (%)1, B.W. = 1/12 Octaves, Axis Y,
Shaker Tri-Axial

Accelerometer

Bruel & Kjaer, Serial 1230045, Range dB48,
Location 1850mm from Base, TT 0541, Channel 5

FIGURE 13
TEST RESPONSE SPECTRUM 1850mm FROM BASE
OF PANEL WITH 10 CONTROLLERS (Y-AXIS)



Test Item

OH 180 Cabinet c/w 10 Controllers, Tele-Radio, Model 701067,
Serial 018, S/C 817-D702

Particulars

May 28/86, Time 1:00, Temp(°C) 23, Humidity(%) 53, Press(kPa) 100.1,
Graph 5749

Specifications

Specs IEEE 344, Conditions Unit #2 Operating in FUNC Mode

Analysis

Type Maximax, Damping (%) 1, B.W. = 1/12 Octaves, Axis Z,
Shaker Tri-Axial

Accelerometer

Bruel & Kjaer, Serial 1234283, Range dB48,
Location 1850mm from Base, TT 0541, Channel 6

FIGURE 14

TEST RESPONSE SPECTRUM 1850mm FROM BASE
OF PANEL WITH 10 CONTROLLERS (Z-AXIS)

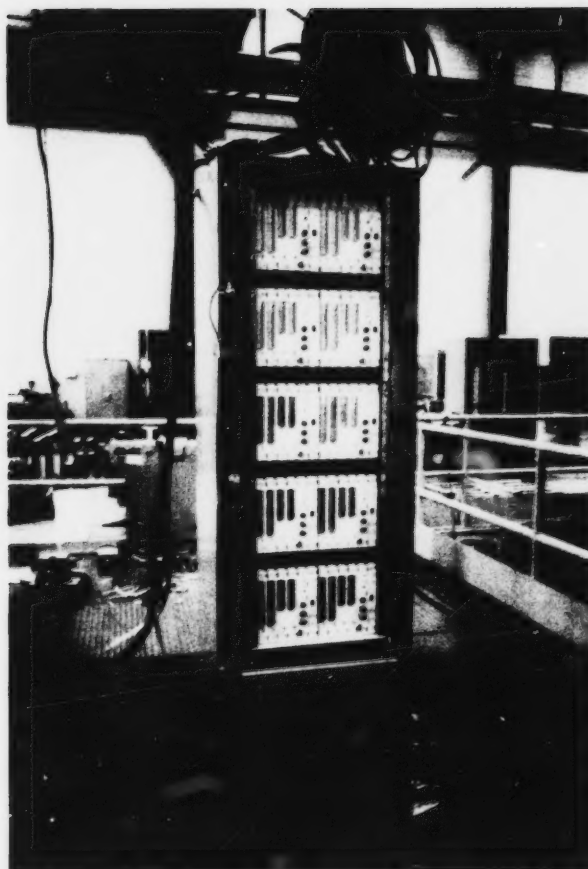
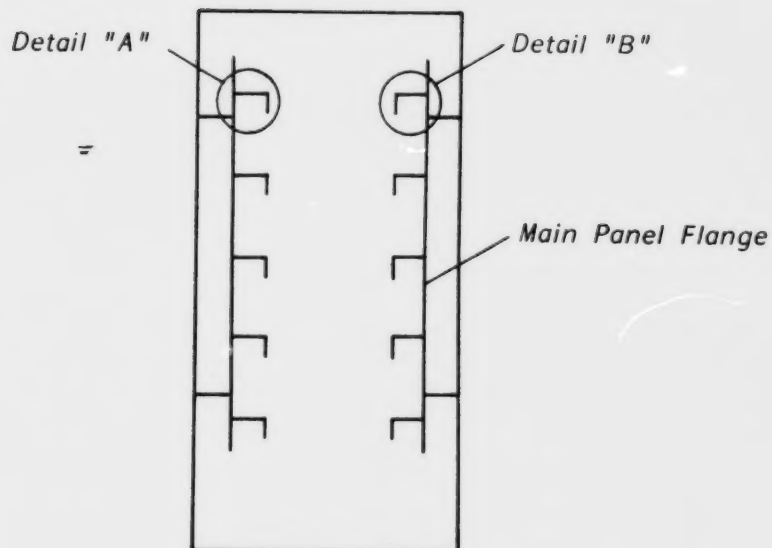
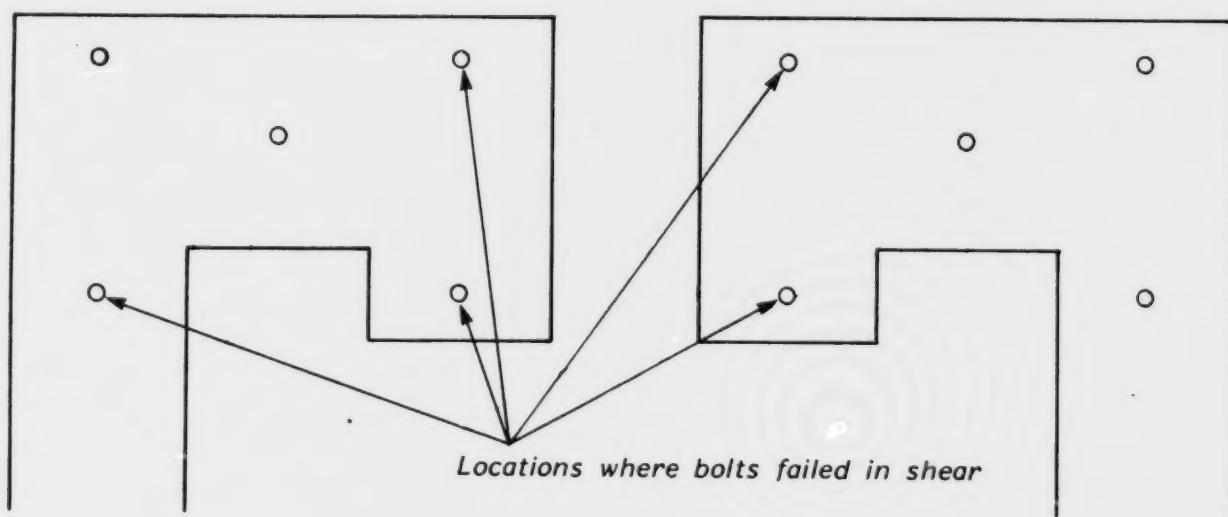


FIGURE 15

OH-180 PROGRAMMABLE CONTROLLER PANEL WITH
10 CONTROLLERS MOUNTED ON
TRI-AXIAL SHAKER TABLE



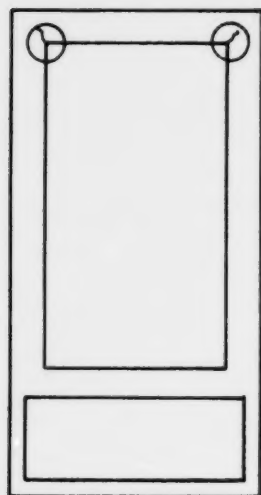
Back View With Door Open



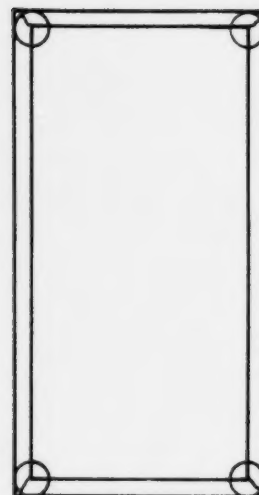
Detail "A"

Detail "B"

FIGURE 16
LOCATIONS OF SHEARED BOLTS FOUND AFTER SHAKER TEST



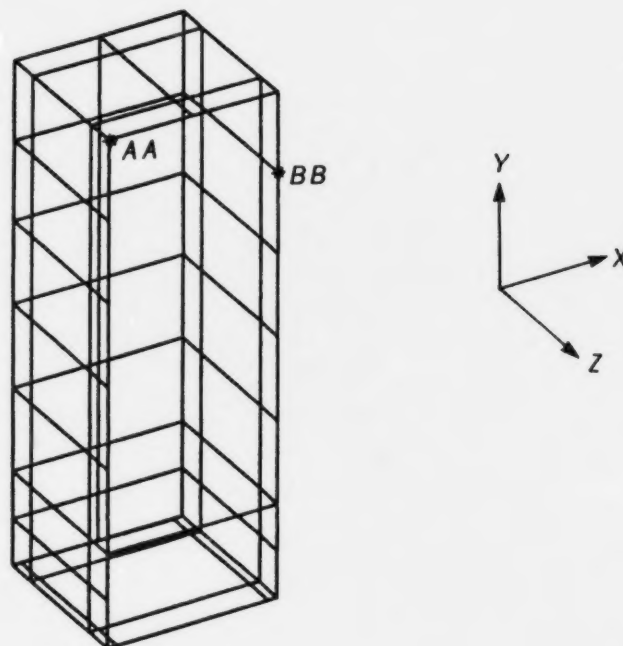
Front View



*Back View
With Door Open*

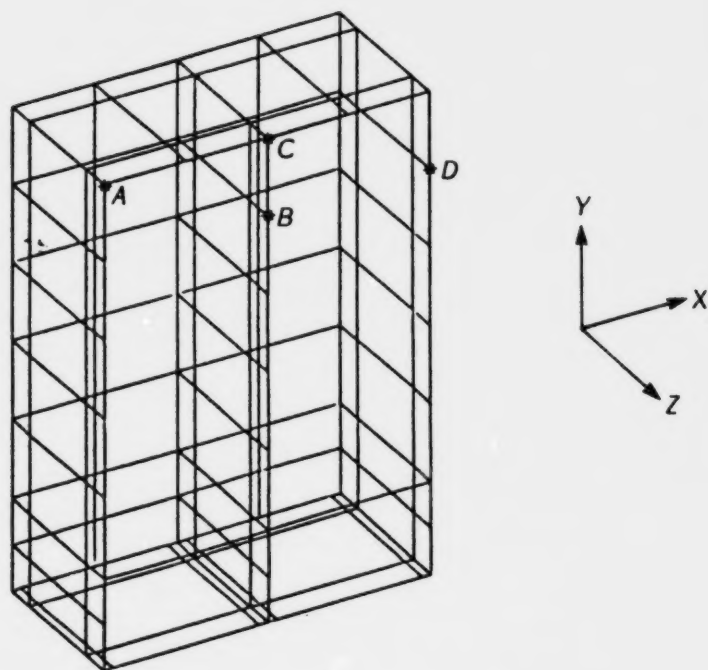
○ *Designates Location*

FIGURE 17
LOCATIONS OF HAIRLINE CRACKS WHICH
OCCURRED AFTER SHAKER TABLE TEST



* Location where secondary response spectra are generated.

FIGURE 18
FINITE ELEMENT MODEL OF
OH-180 PROGRAMMABLE CONTROLLER PANEL



* Location where secondary response spectra are generated.

FIGURE 19
FINITE ELEMENT MODEL OF
TWO PANEL LINE-UP ASSEMBLY

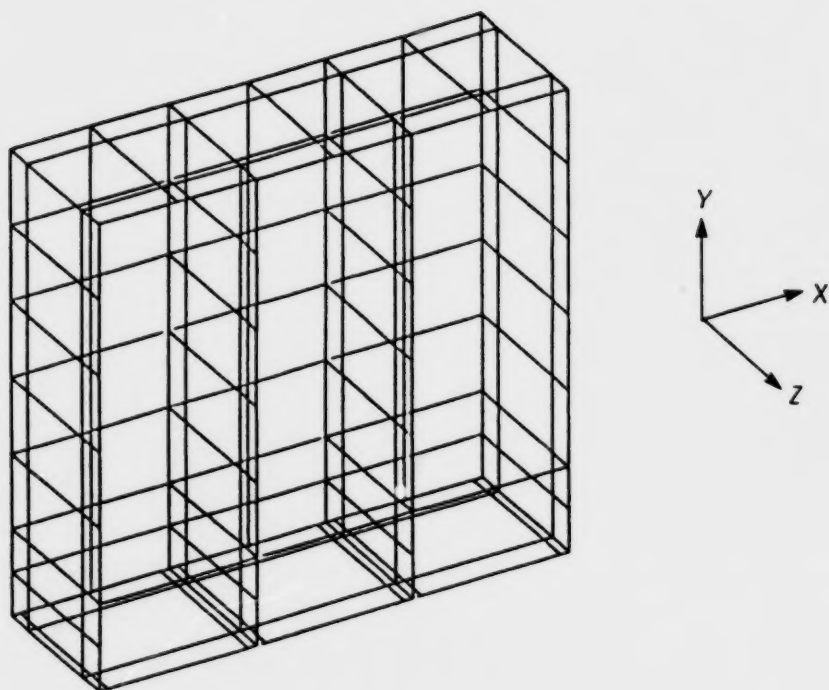
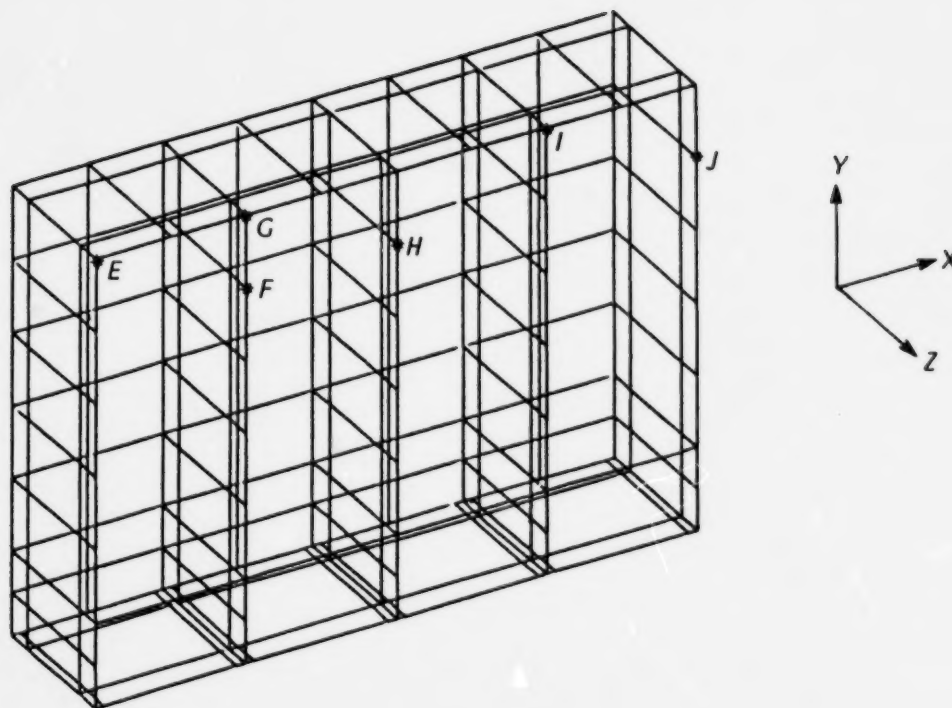
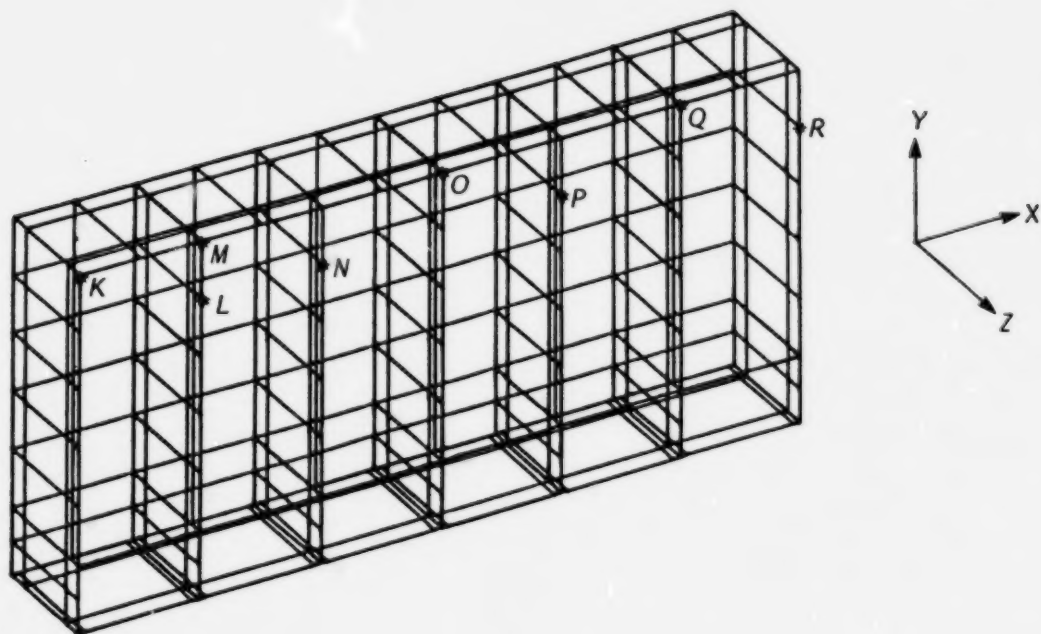


FIGURE 20
FINITE ELEMENT MODEL OF
THREE PANEL LINE-UP ASSEMBLY



* Location where secondary response spectra are generated.

FIGURE 21
FINITE ELEMENT MODEL OF
FOUR PANEL LINE-UP ASSEMBLY



♦Location where secondary response spectra are generated.

FIGURE 22
FINITE ELEMENT MODEL OF
SIX PANEL LINE-UP ASSEMBLY

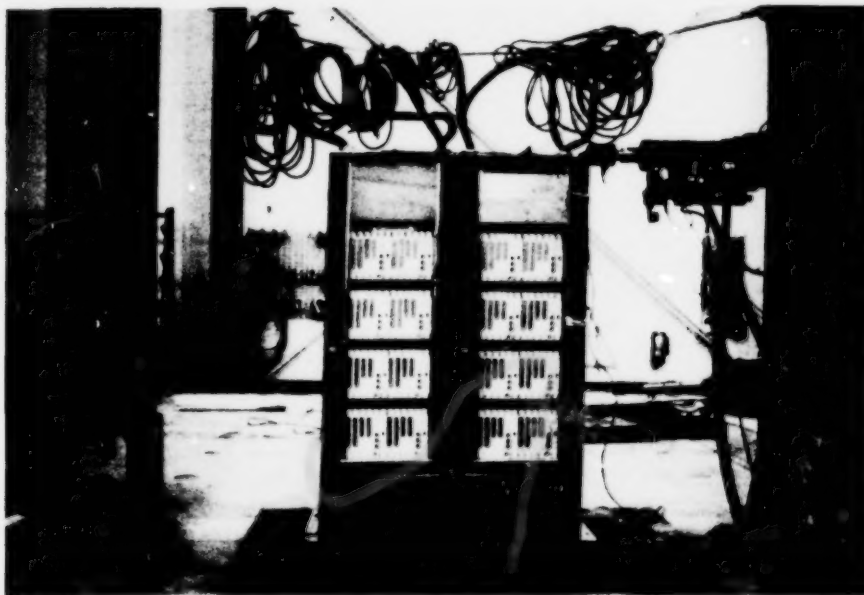


FIGURE 23
EXPERIMENTAL MODAL TEST ARRANGEMENT OF
TWO PANEL LINEUP ASSEMBLY

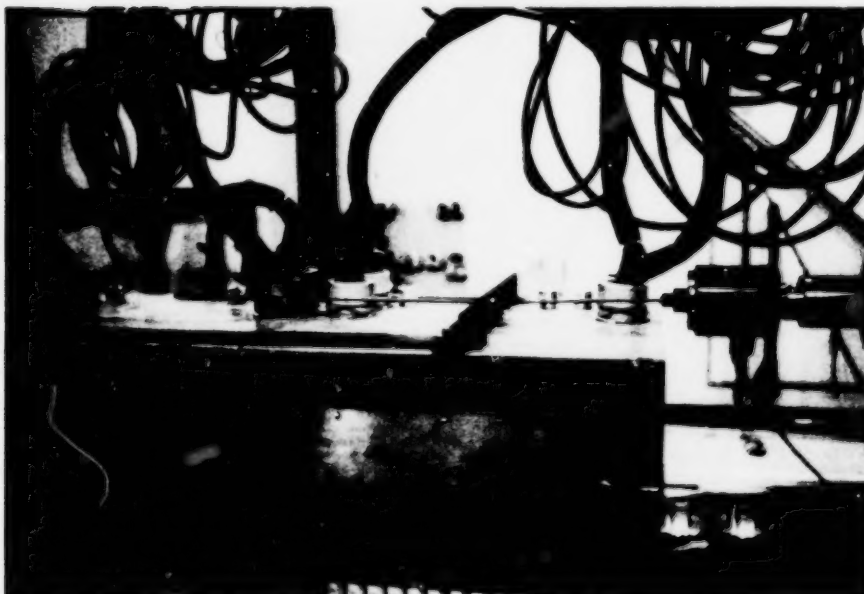
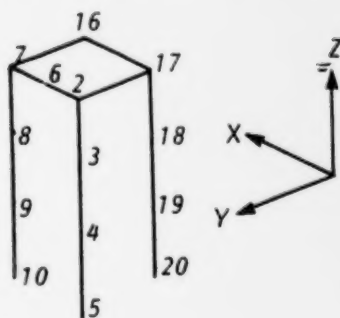
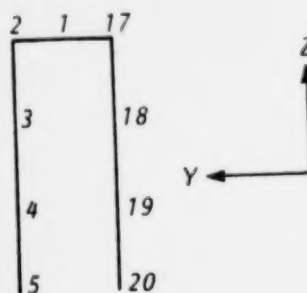


FIGURE 24
MECHANICAL CONNECTION OF OH-180 CABINETS
FOR MODAL TESTS

Oblique View



Side View



Front View

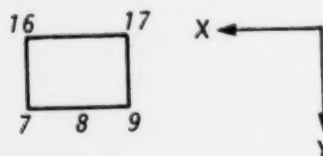
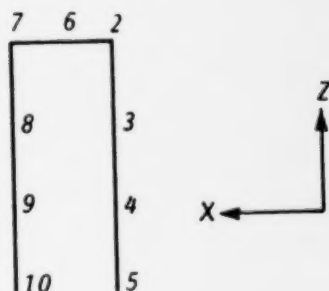


FIGURE 25

OH-180 SINGLE PANEL SHOWING
LOCATIONS WHERE RESPONSE MEASURED

- Note: - Sweep sinusoid force applied at location #1 in X-direction.
- Locations 5, 10 and 20 are 50.8cm vertical from floor anchor.

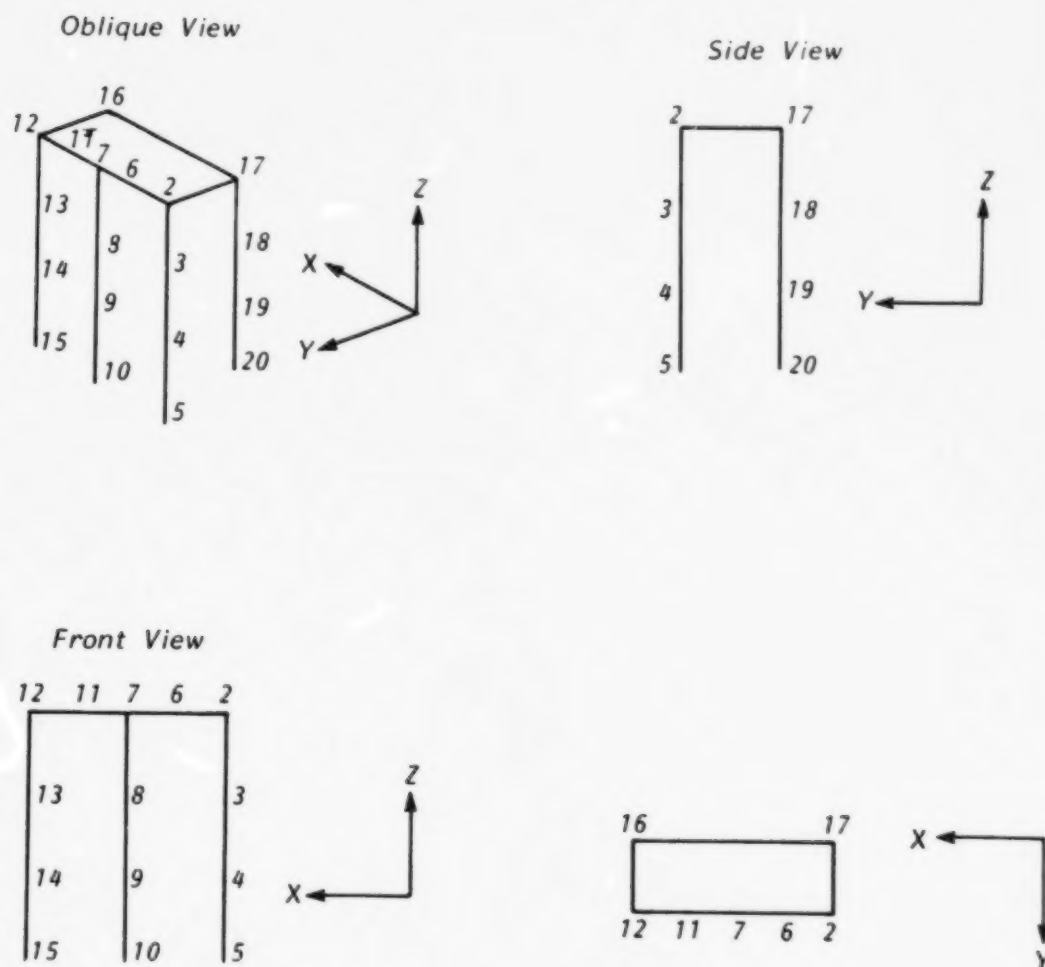
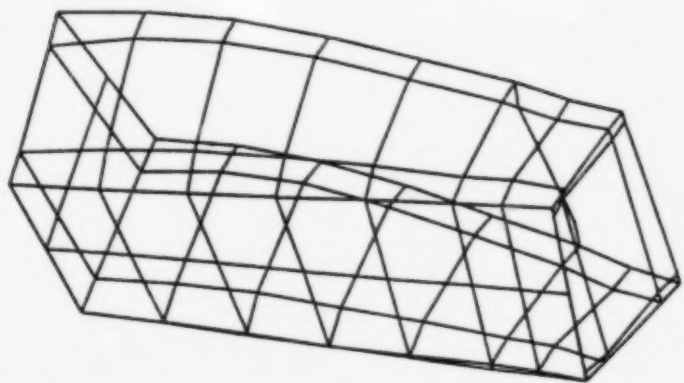


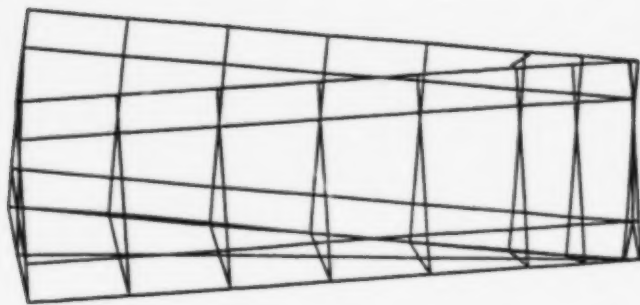
FIGURE 26

OH-180 DUAL PANELS ATTACHED TOGETHER
SHOWING LOCATIONS WHERE RESPONSE MEASURED

- Note: - Sweep sinusoid force applied at mid-point between locations #2 and #17 in X-direction.
- Locations 5, 10, 15 and 20 are 50.8cm vertical from the floor anchor.

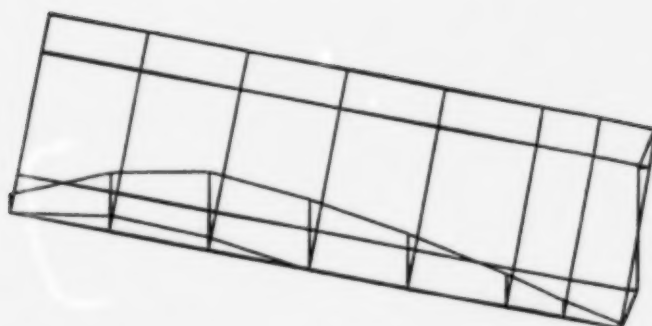


Oblique View

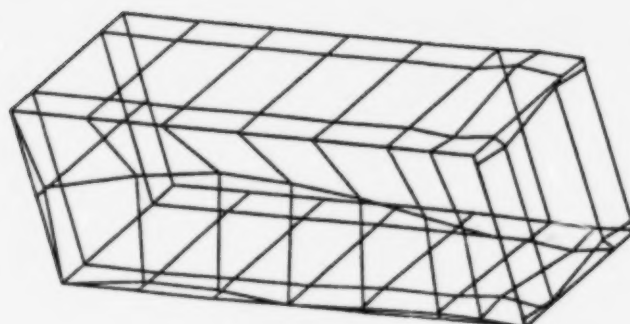


Side View

FIGURE 27
FIRST VIBRATION MODE OF A SINGLE OH-180 PANEL
FREQUENCY = 12.2 Hz



Side View



Oblique View

FIGURE 28
SECOND VIBRATION MODE OF A SINGLE OH-180 PANEL
FREQUENCY = 16.1 Hz

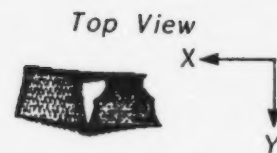
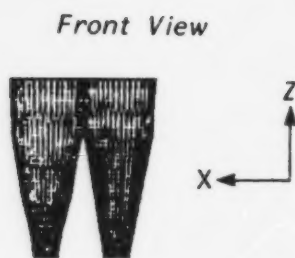
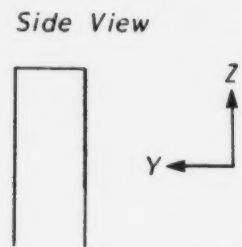
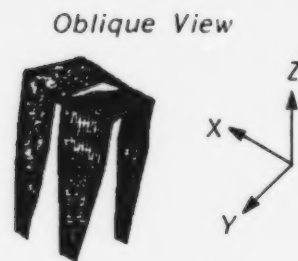
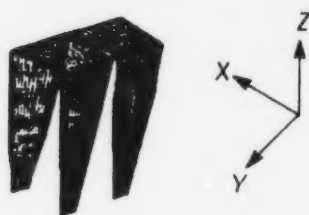
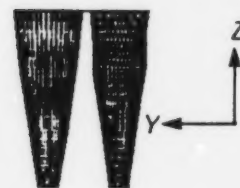


FIGURE 29
OH-180 SINGLE PANEL MODE SHAPE AT 13.1 Hz

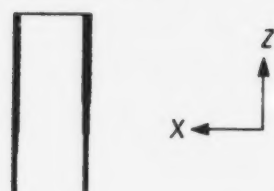
Oblique View



Side View



Front View



Top View

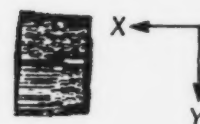
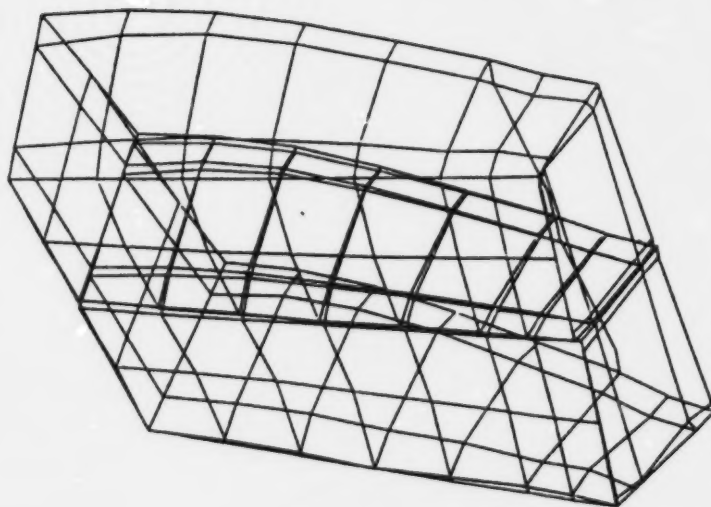
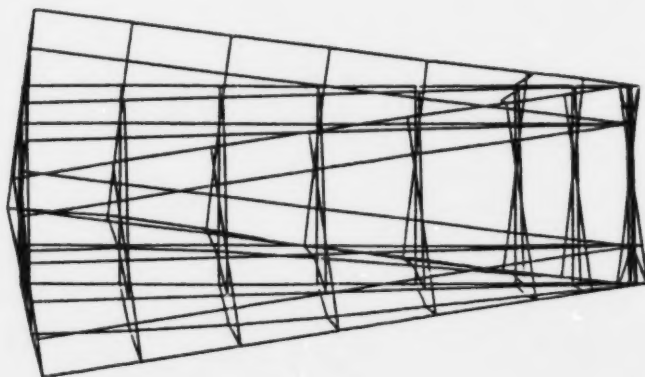


FIGURE 30

OH-180 SINGLE PANEL MODE SHAPE AT 16.0 Hz

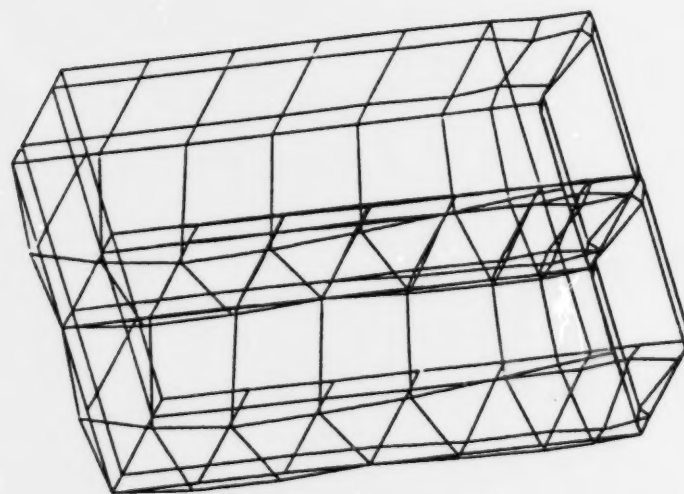


Oblique View

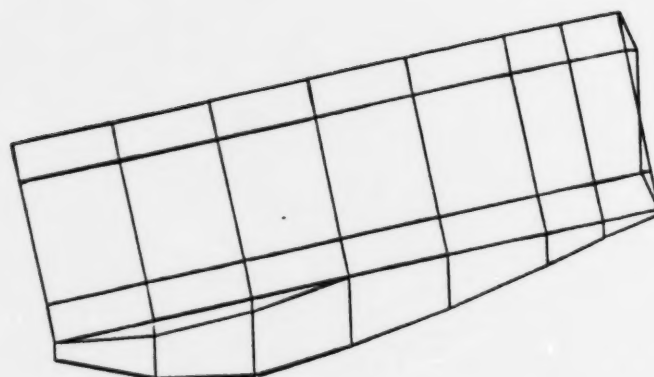


Side View

FIGURE 31
FIRST VIBRATION MODE OF TWO PANEL LINE-UP ASSEMBLY
FREQUENCY = 12.5 Hz



Oblique View



Side View

FIGURE 32
SECOND VIBRATION MODE OF TWO PANEL LINE-UP ASSEMBLY
FREQUENCY = 15.9 Hz

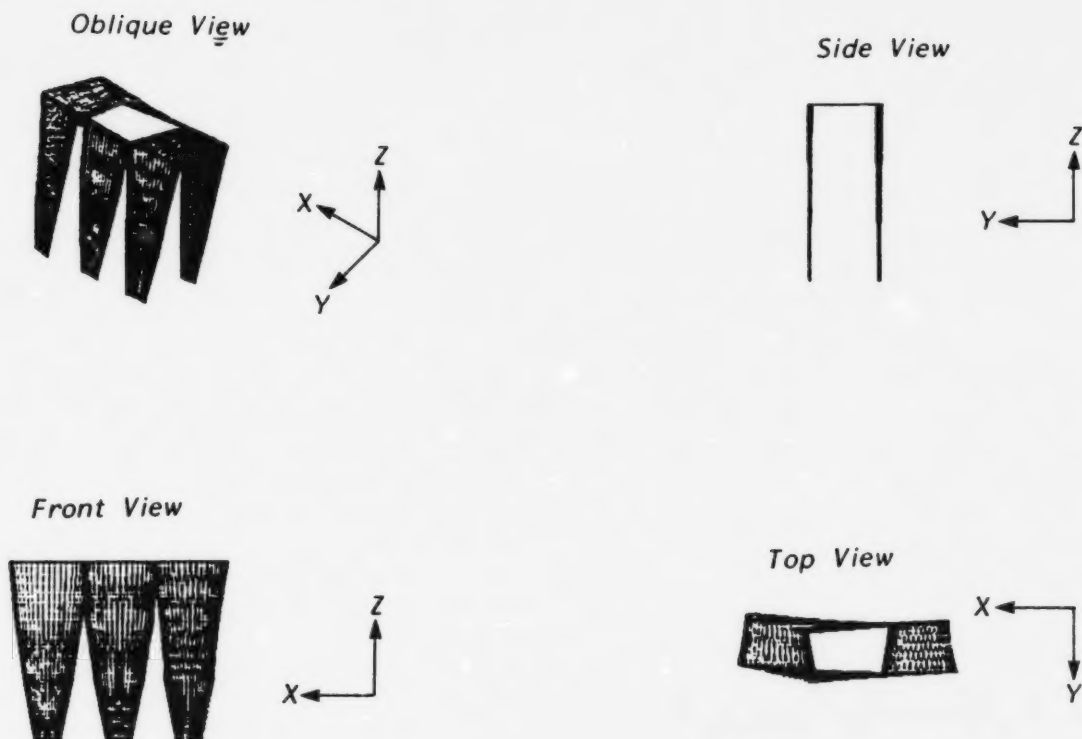


FIGURE 33
OH-180 DUAL PANEL MODE SHAPE AT 12.8 Hz

h

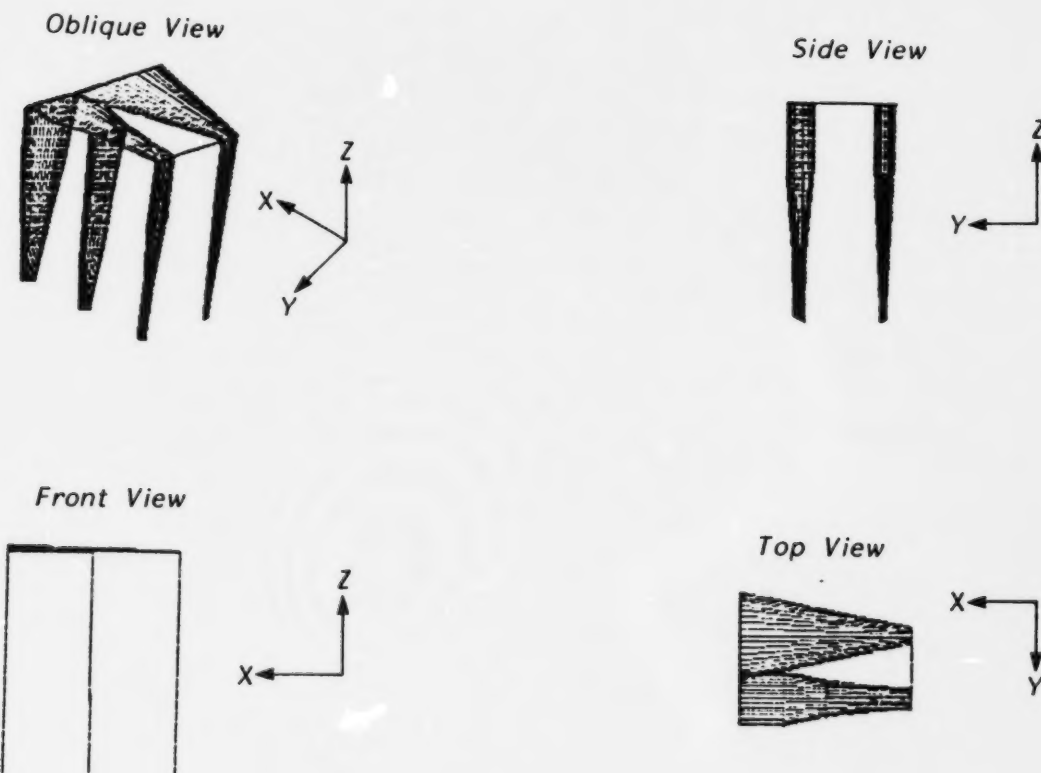
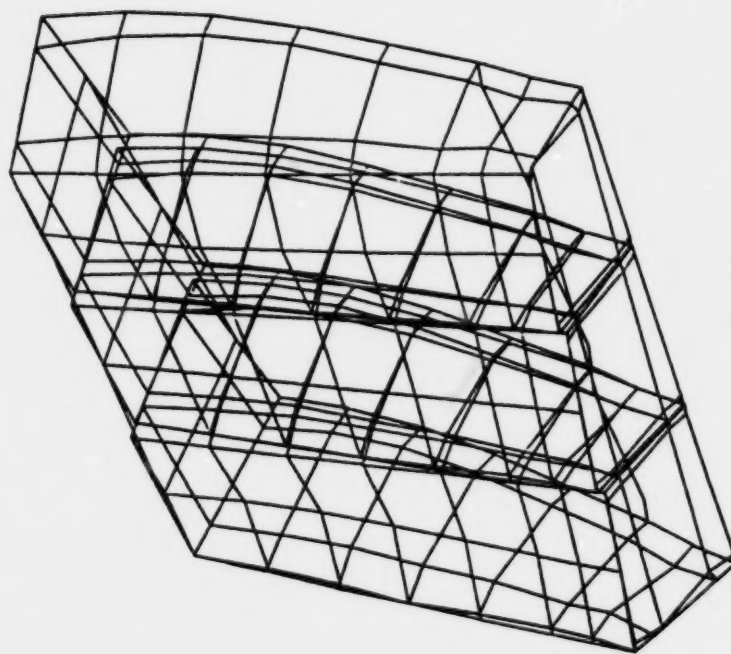
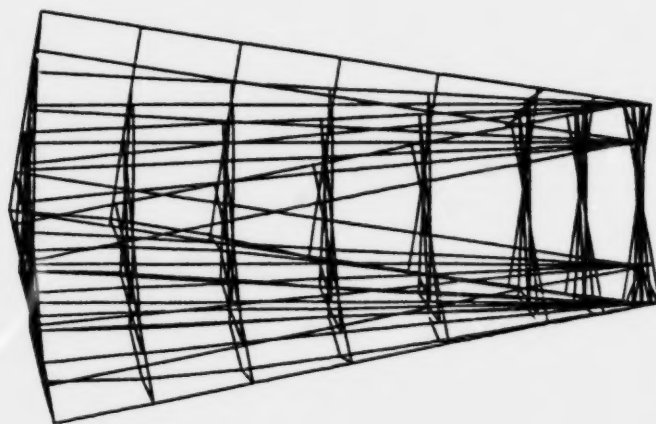


FIGURE 34
OH-180 DUAL PANEL MODE SHAPE AT 14.5 Hz

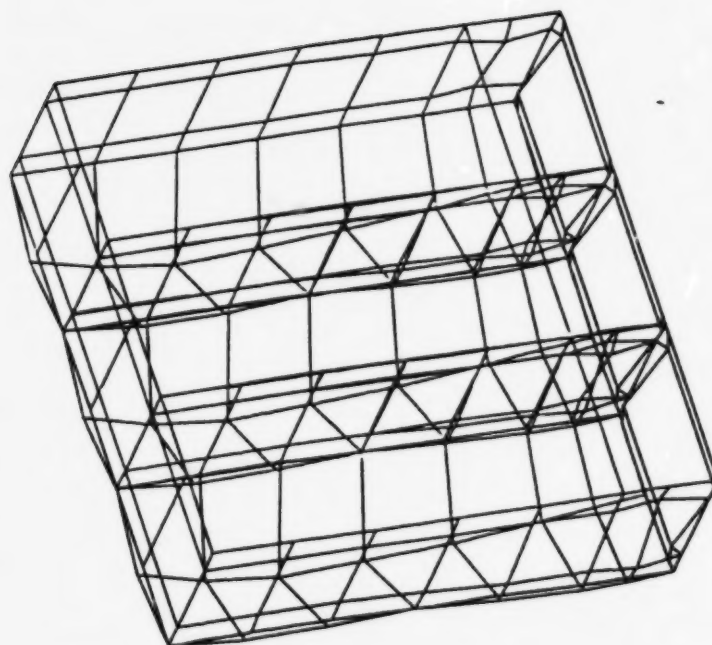


Oblique View

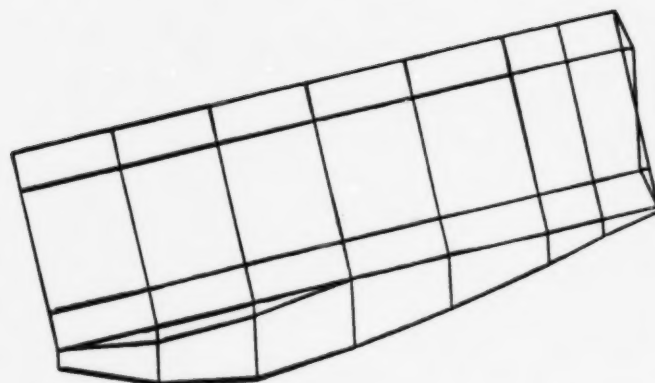


Side View

FIGURE 35
FIRST VIBRATION MODE OF THREE PANEL LINE-UP ASSEMBLY
FREQUENCY = 12.7 Hz

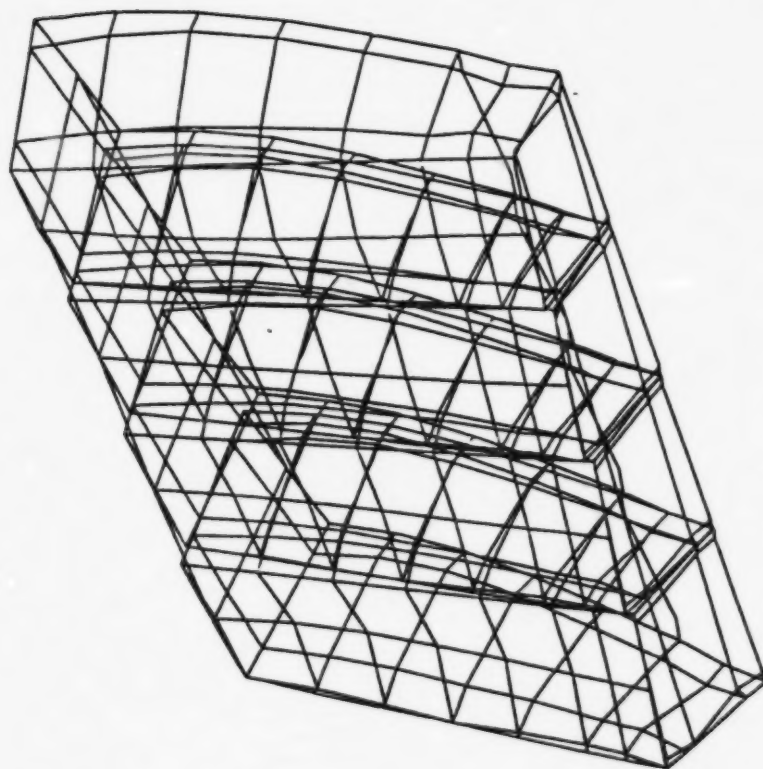


Oblique View

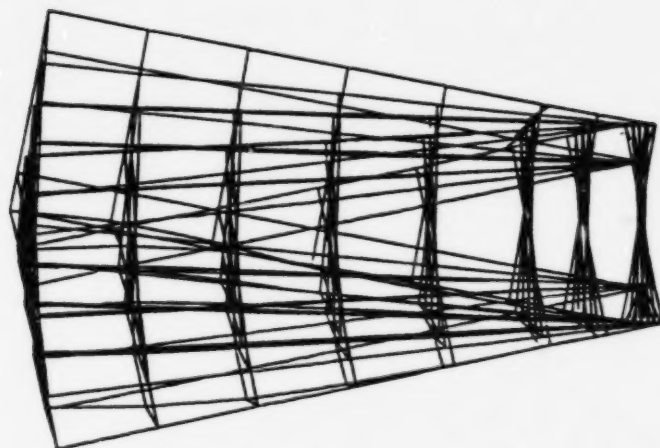


Side View

FIGURE 36
SECOND VIBRATION MODE OF THREE PANEL LINE-UP ASSEMBLY
FREQUENCY = 15.9 Hz

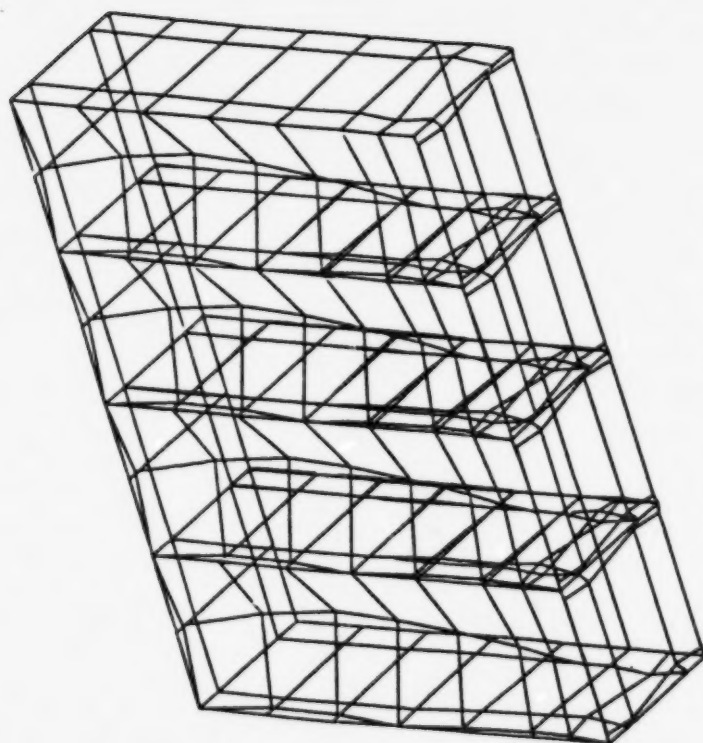


Oblique View

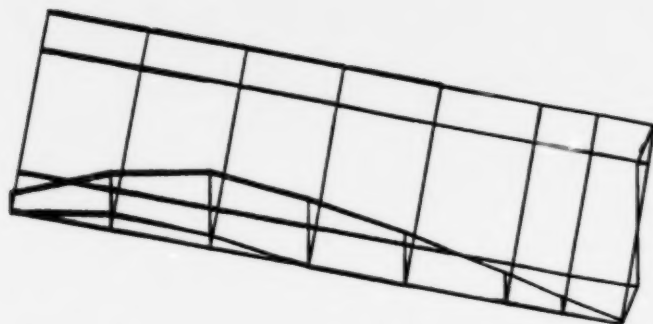


Side View

FIGURE 37
FIRST VIBRATION MODE OF FOUR PANEL LINE-UP ASSEMBLY
FREQUENCY = 12.9 Hz



Oblique View



Side View

FIGURE 38
SECOND VIBRATION MODE OF FOUR PANEL LINE-UP ASSEMBLY
FREQUENCY = 15.9 Hz



Oblique View

FIGURE 39
FIRST VIBRATION MODE OF SIX PANEL LINE-UP ASSEMBLY
FREQUENCY = 13.2 Hz

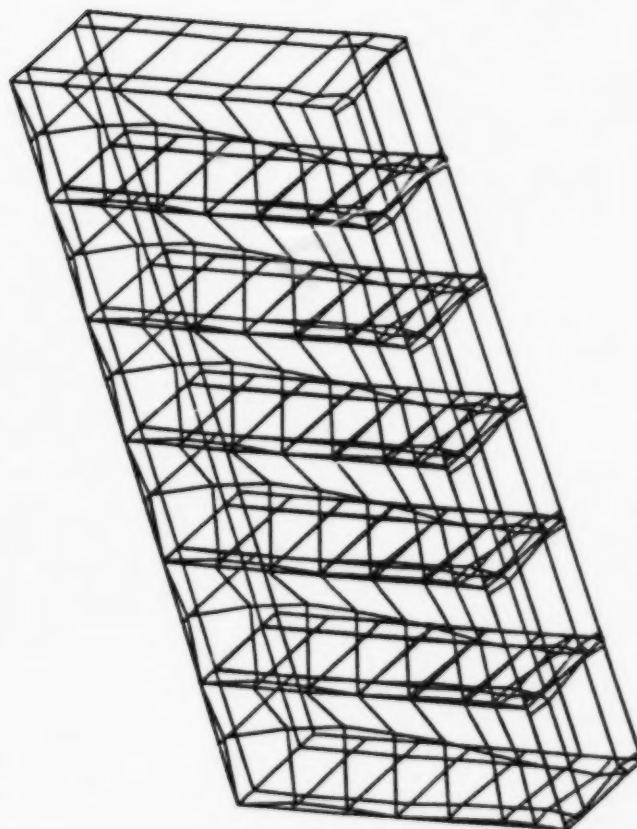
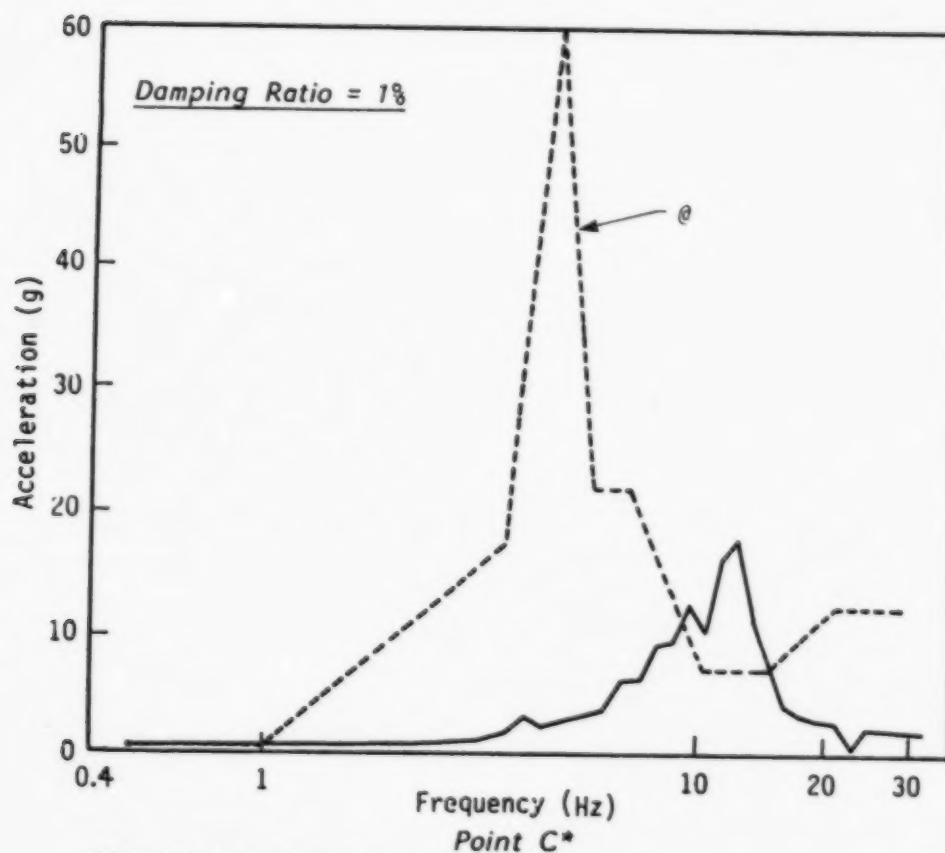
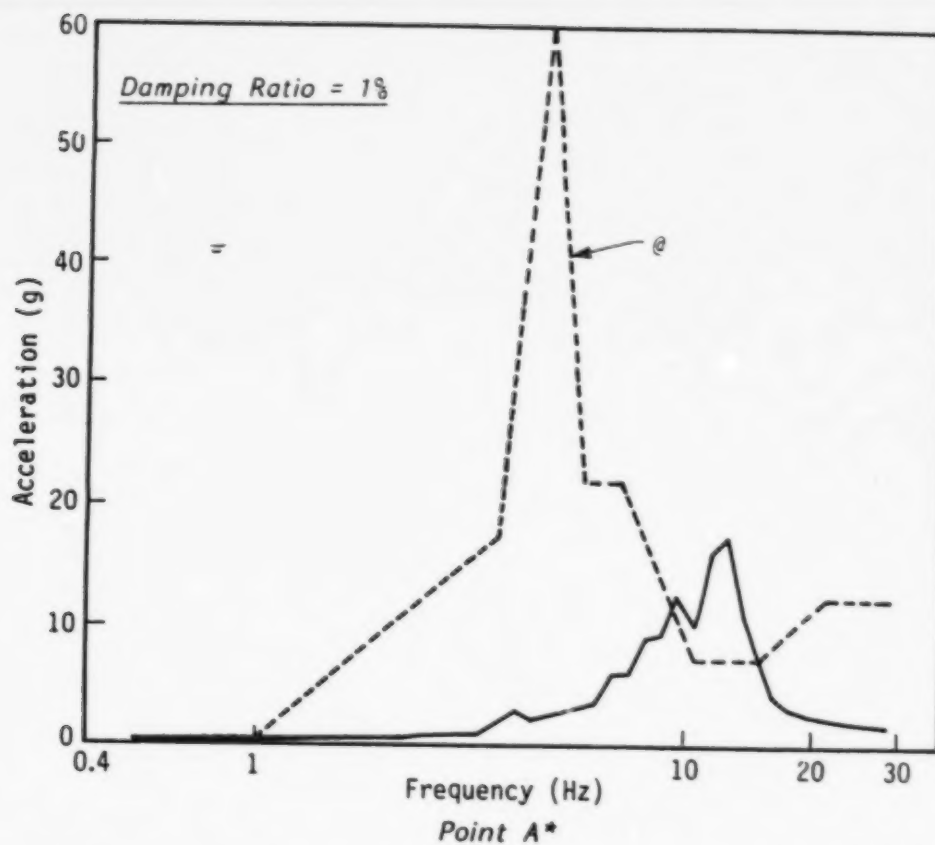


FIGURE 40
SECOND VIBRATION MODE OF SIX PANEL LINE-UP ASSEMBLY
FREQUENCY = 15.8 Hz

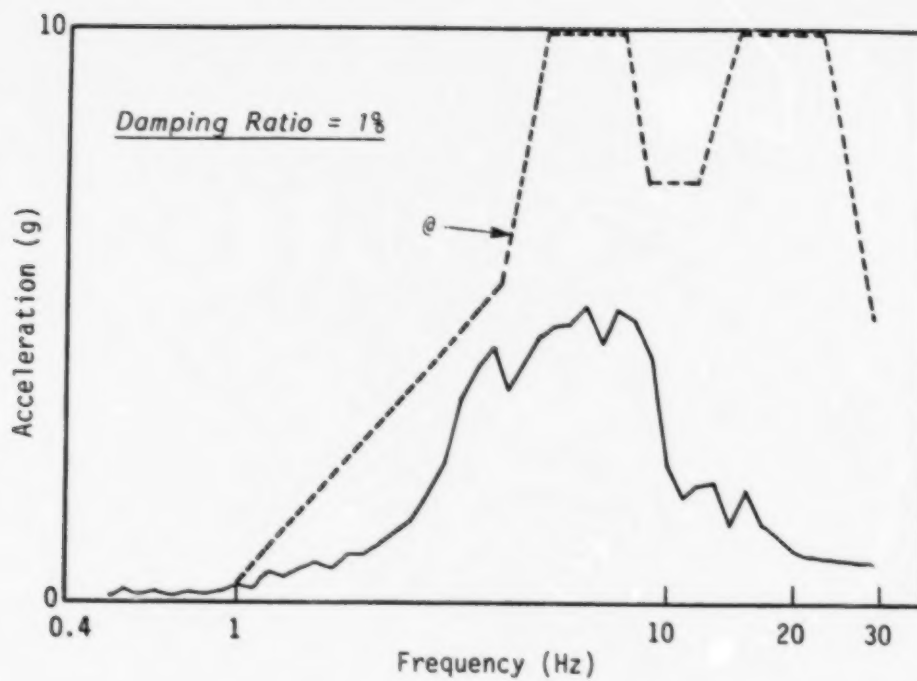


*See Figure 19 for exact location.

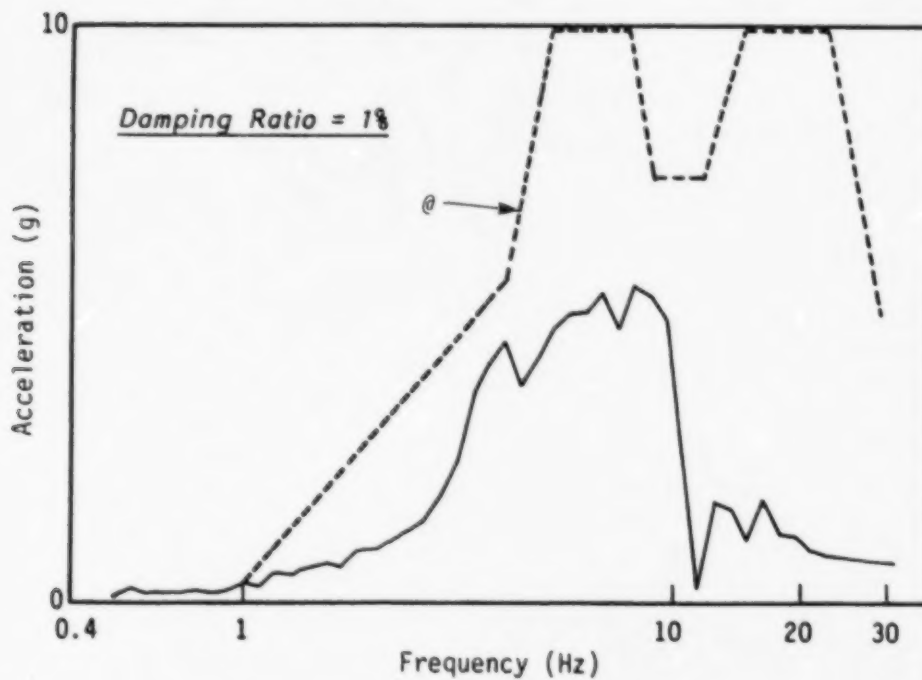
@ Test Response Spectrum (from Figure 12).

FIGURE 41

SECONDARY RESPONSE SPECTRA GENERATED
ON TWO PANEL LINE-UP MODEL (X-AXIS)



Point A*



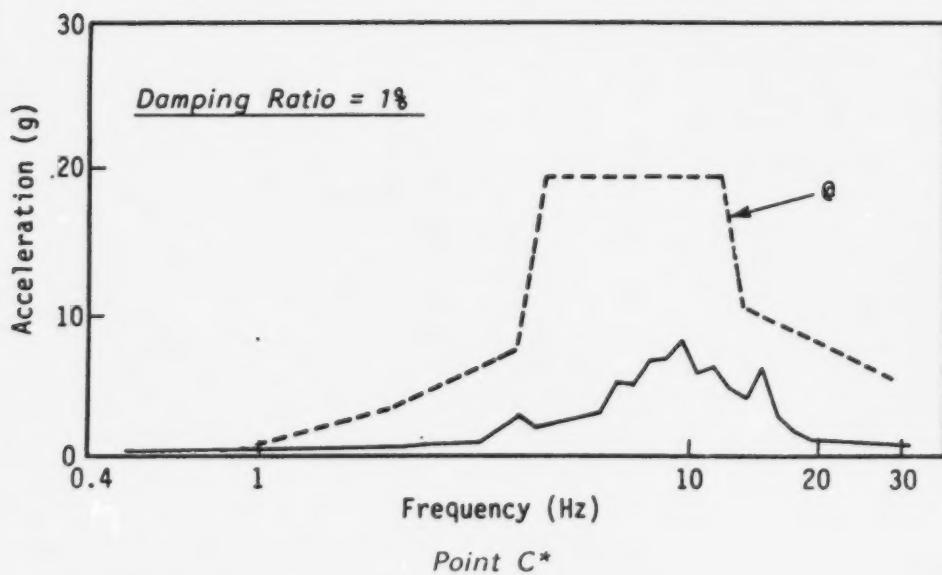
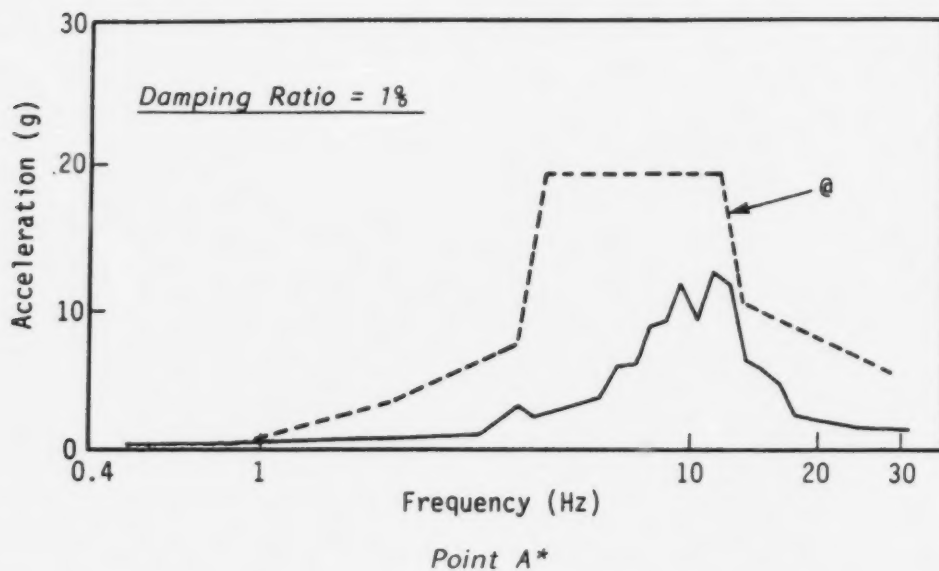
Point C*

@ Test Response Spectrum (from Figure 13).

* See Figure 19 for exact location.

FIGURE 42

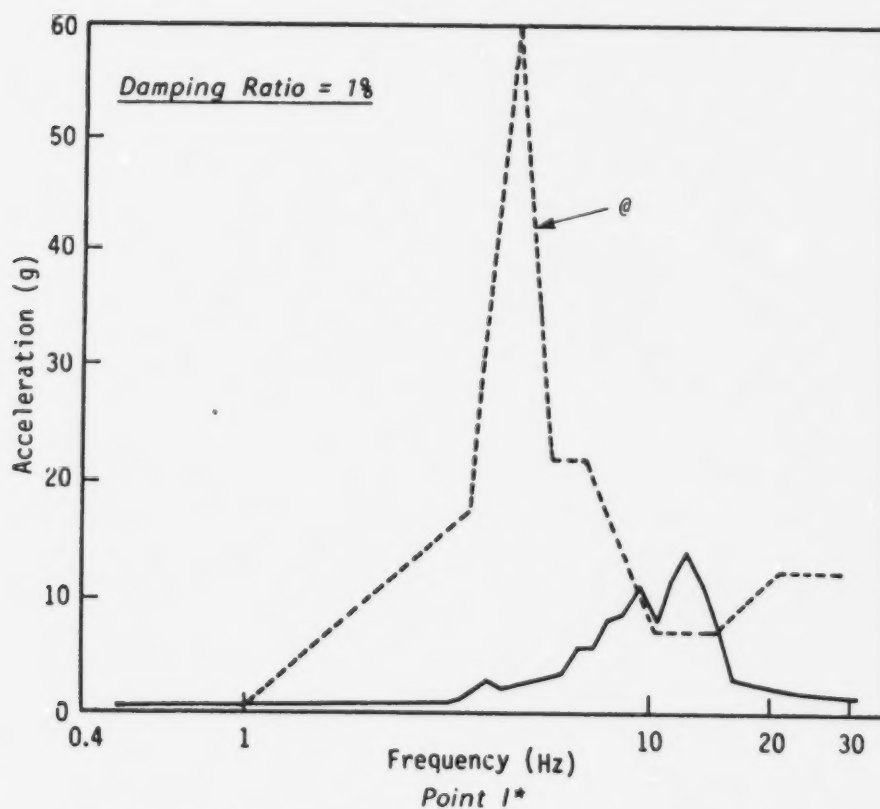
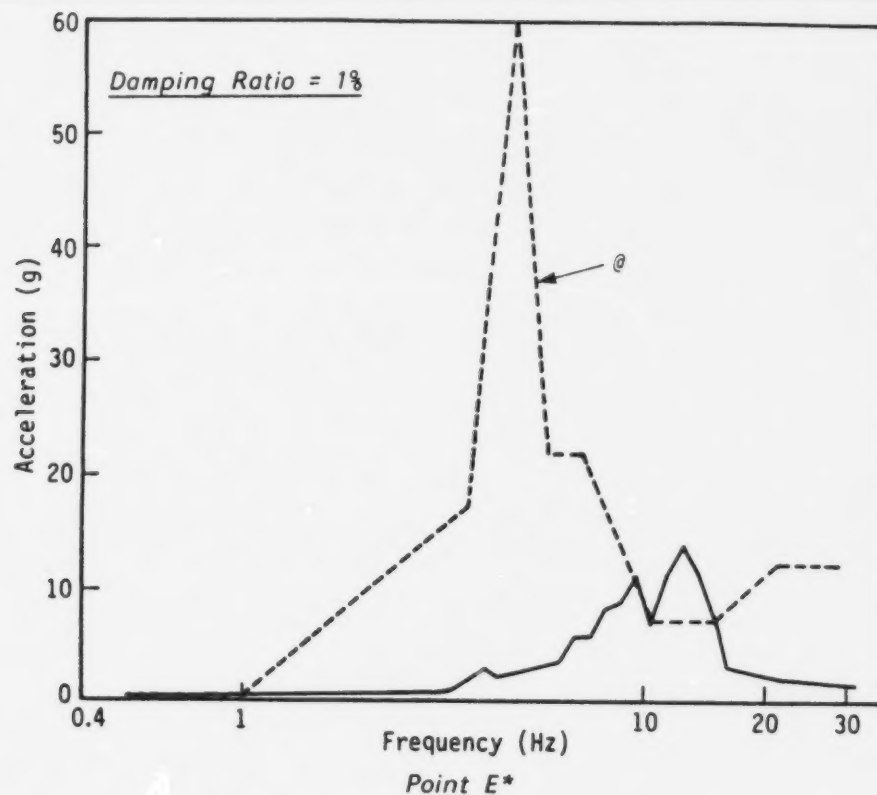
SECONDARY RESPONSE SPECTRA GENERATED
ON TWO PANEL LINE-UP MODEL (Y-AXIS)



* See Figure 19 for exact location.

@ Test Response Spectrum (from Figure 14).

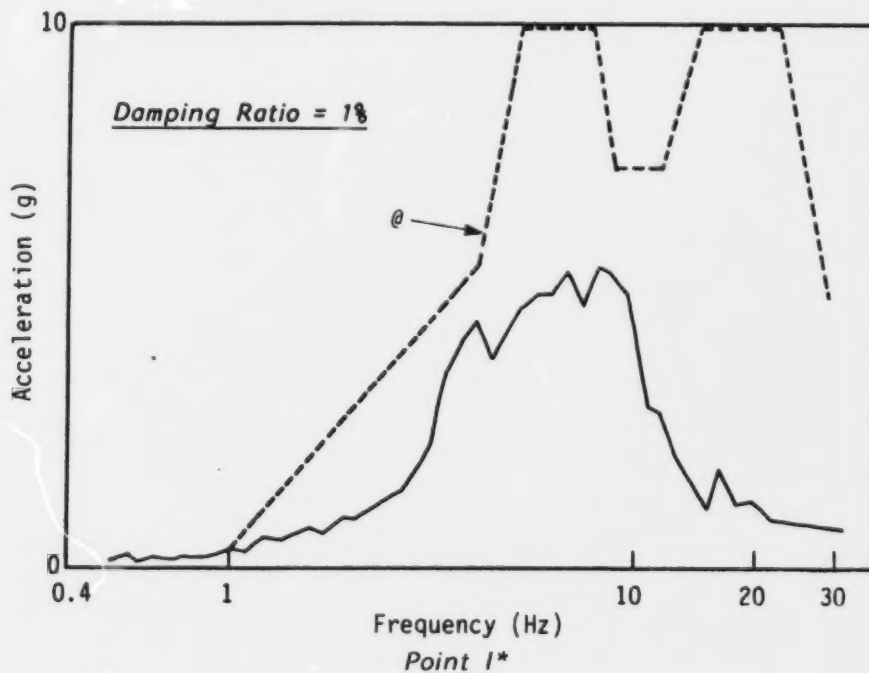
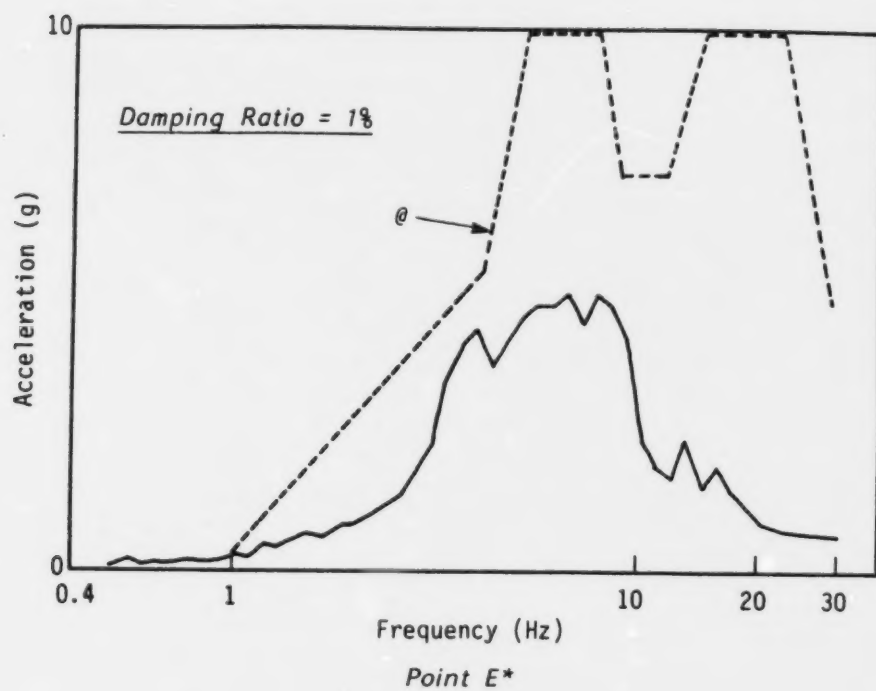
FIGURE 43
SECONDARY RESPONSE SPECTRA GENERATED
ON TWO PANEL LINE-UP MODEL (Z-AXIS)



*See Figure 21 for exact location.
 @ Obtained From Figure 12.

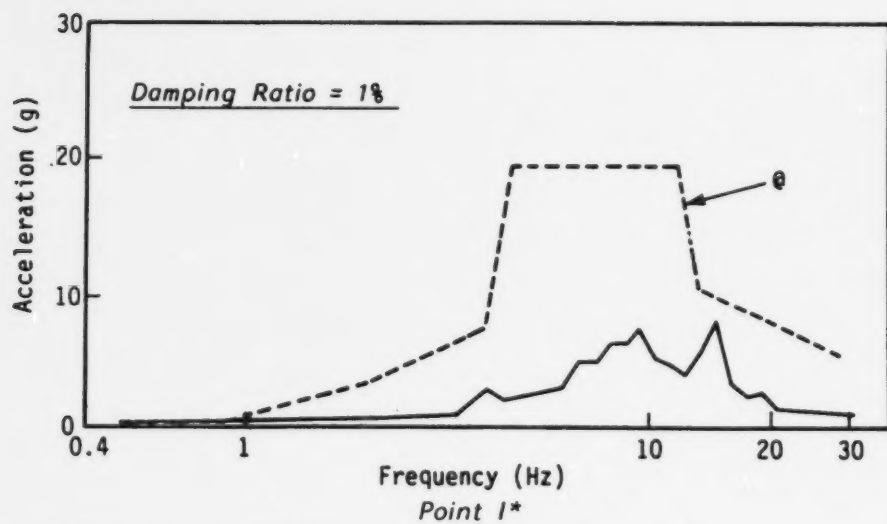
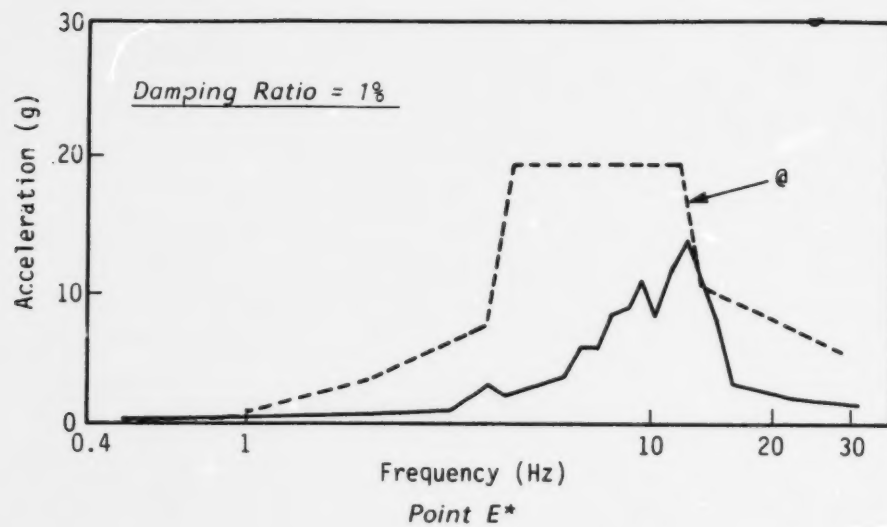
FIGURE 44

SECONDARY RESPONSE SPECTRA GENERATED
 ON FOUR PANEL LINE-UP MODEL (X-AXIS)



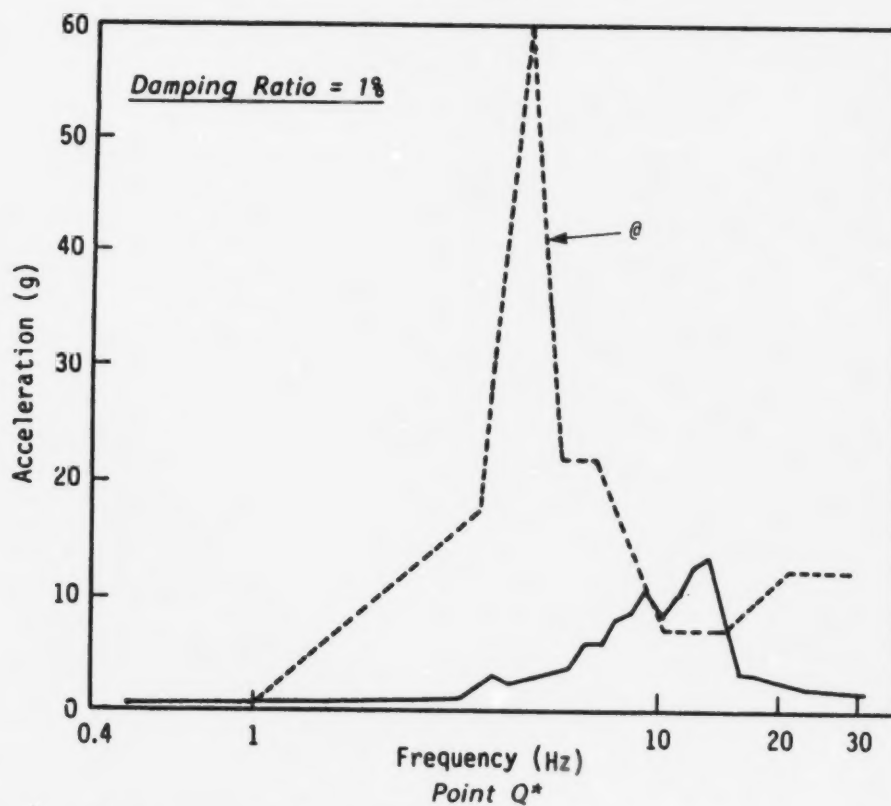
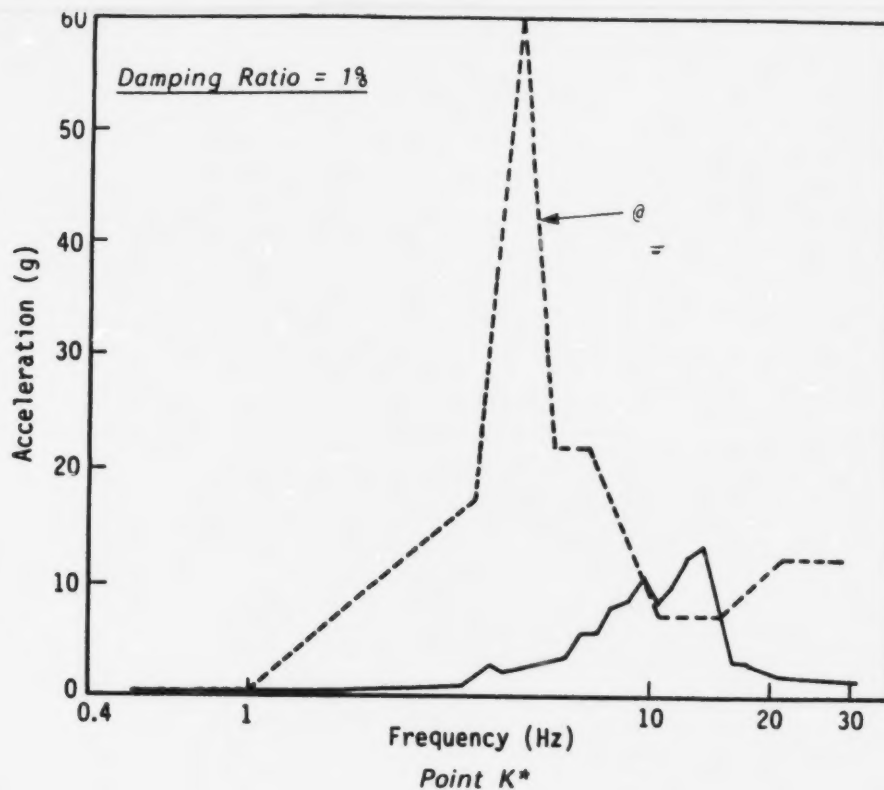
*See Figure 21 for exact location.
 @ Obtained from Figure 13.

FIGURE 45
 SECONDARY RESPONSE SPECTRA GENERATED
 ON FOUR PANEL LINE-UP MODEL (Y-AXIS)



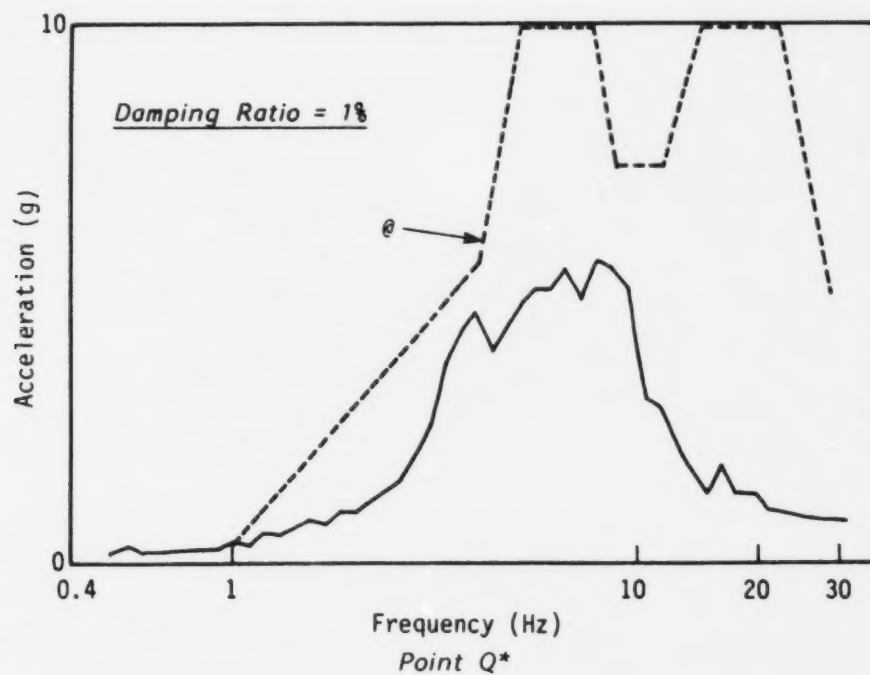
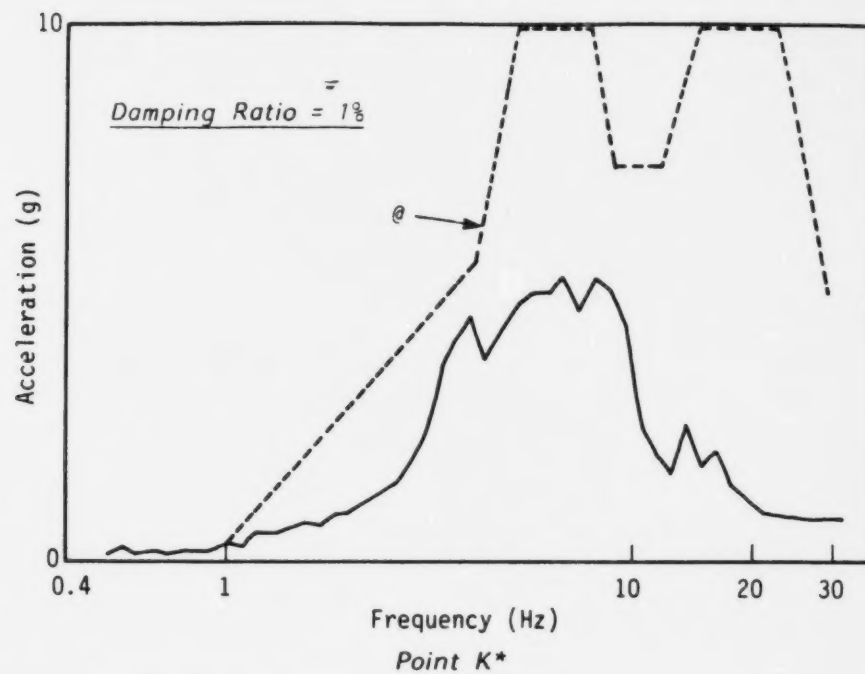
*See Figure 21 for exact location.
 ② Obtained from Figure 14.

FIGURE 46
 SECONDARY RESPONSE SPECTRA GENERATED
 ON FOUR PANEL LINE-UP MODEL (Z-AXIS)



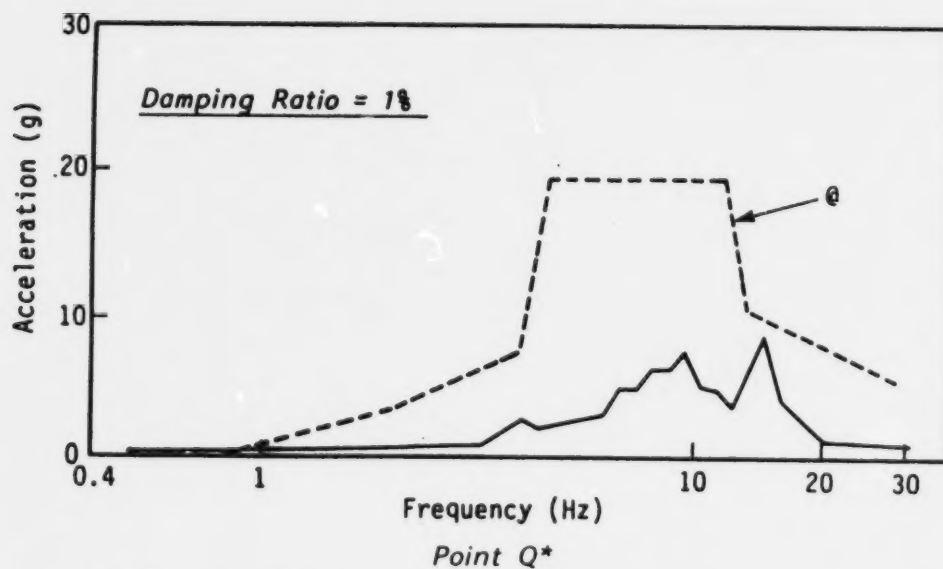
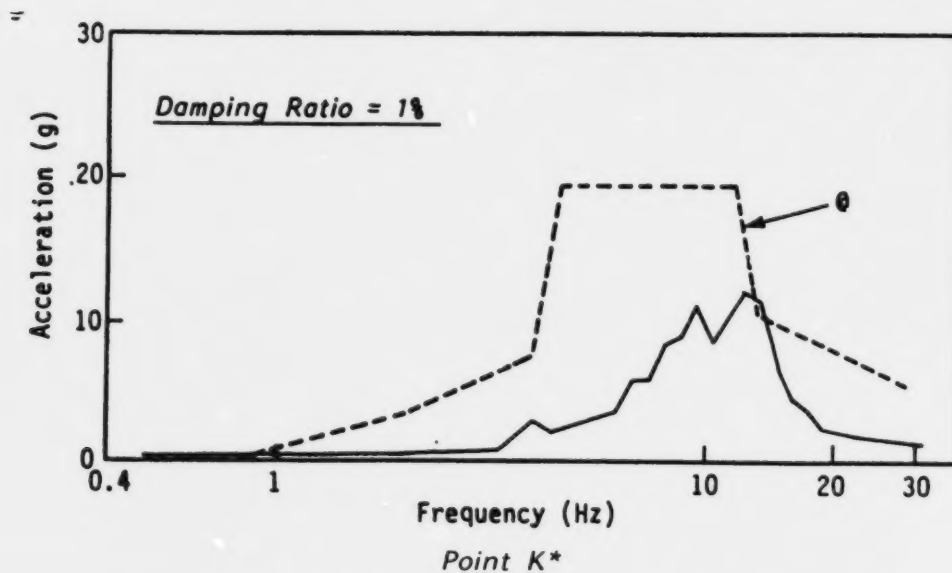
*See Figure 22 for exact location.
 @ Obtained from Figure 12.

FIGURE 47
 SECONDARY RESPONSE SPECTRA GENERATED
 ON SIX PANEL LINE-UP MODEL (X-AXIS)



*See Figure 22 for exact location.
 @ Obtained from Figure 13.

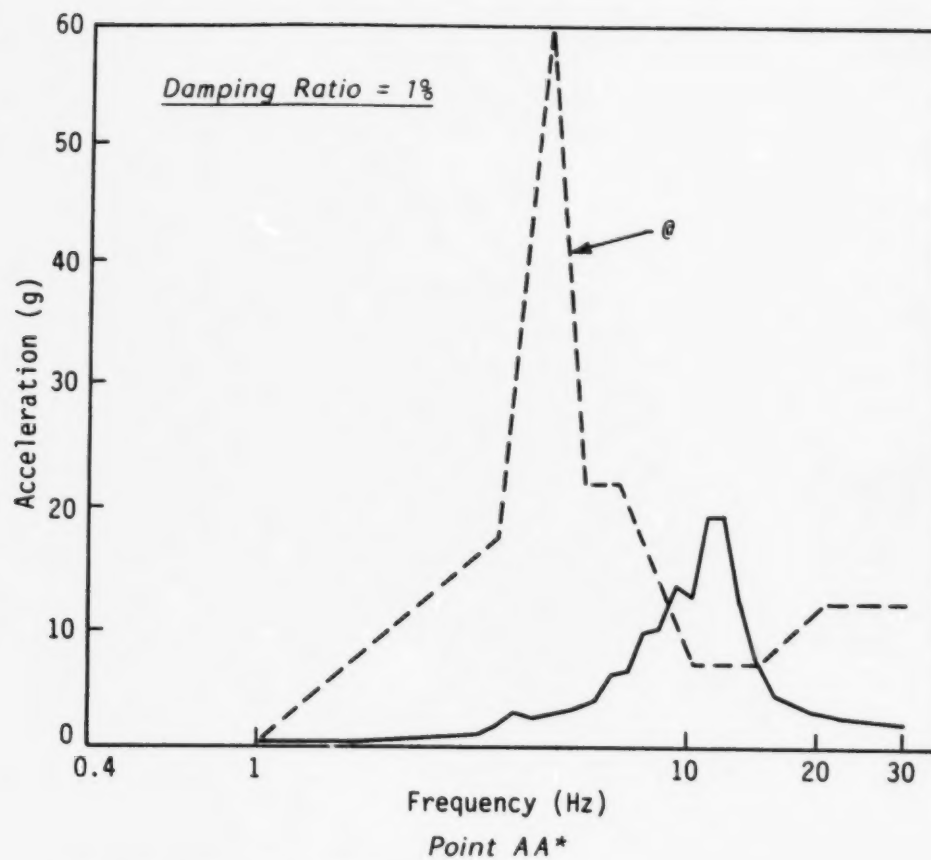
FIGURE 48
 SECONDARY RESPONSE SPECTRA GENERATED
 ON SIX PANEL LINE-UP MODEL (Y-AXIS)



@ Obtained from Figure 14.

* See Figure 22 for exact location.

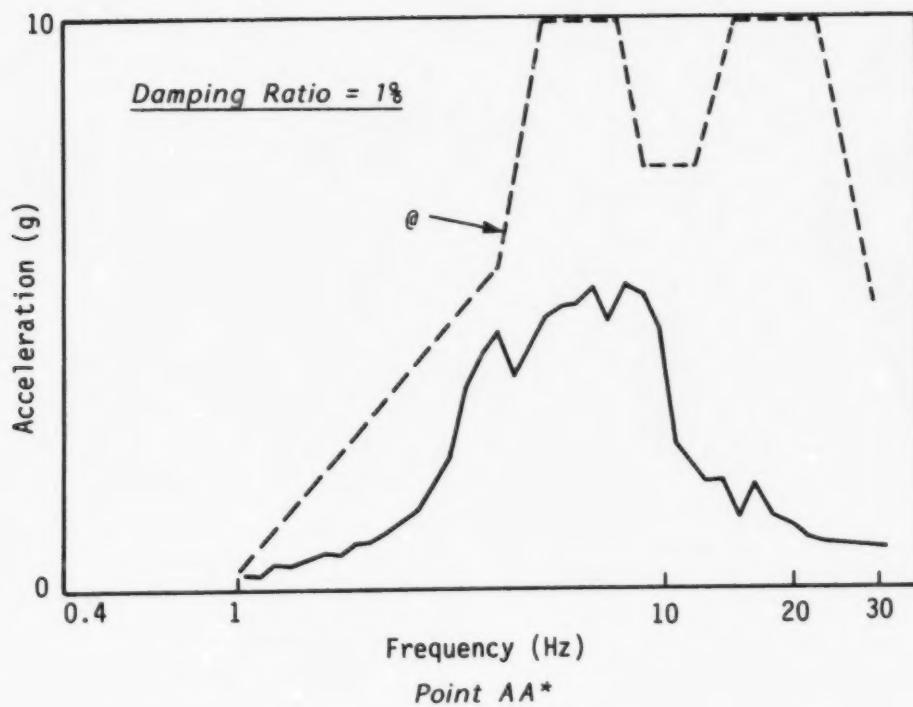
FIGURE 49
SECONDARY RESPONSE SPECTRA GENERATED
ON SIX PANEL LINE-UP MODEL (Z-AXIS)



* See Figure 18 for exact location.

@ Test Response Spectrum (from Figure 12).

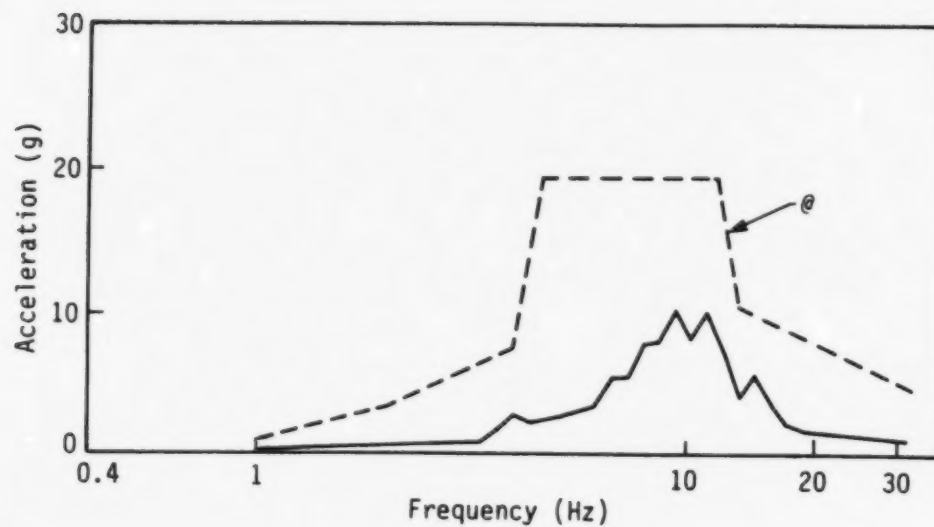
FIGURE 50
SECONDARY RESPONSE SPECTRUM GENERATED
ON SINGLE PANEL MODEL (X-AXIS)



* See Figure 18 for exact location.

@ Test Response Spectrum (obtained from Figure 13).

FIGURE 51
SECONDARY RESPONSE SPECTRUM GENERATED
ON SINGLE PANEL MODEL (Y-AXIS)



Point AA*

* See Figure 18 for exact location.

@ Test Response Spectrum (from Figure 14).

FIGURE 52
SECONDARY RESPONSE SPECTRUM GENERATED
ON SINGLE PANEL MODEL (Z-AXIS)

APPENDIX A

QUALIFICATION PLAN

Seismic Qualification Program for OH-180
Programmable Controller Panels

Darlington Nuclear Generating Station

For: Darlington Engineering Department
(Attention, Mr. I.B. Berezowsky,
H16G27)

File: NK38-60800P

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Revision: 2
Date: September 8, 1986

(1)

1.0 INTRODUCTION AND SCOPE

This document, which forms the basis for the seismic qualification of OH-180 Programmable Controller panels is prepared by Ontario Hydro's Research Division for the Darlington Nuclear Generating Station.

1.1 Objective

The objective of this qualification plan is to present the approach and procedures that will be used to demonstrate the seismic qualification of OH-180 programmable controller panels. The equipment qualified will be used to provide essential services to safety related systems.

The purpose of seismic qualification is to demonstrate that the equipment can withstand the stresses of a design basis earthquake (DBE) and still perform its safety related function.

1.2 Reference Documents

The following documents will be used as guides in this qualification program:

- * Ontario Hydro Specification STD5-X-50090-0002 "Seismic Qualification of Electrical Equipment and Components", Design and Construction Branch, Electrical Design Department, Issued November, 1979.
- * IEEE Std 344 (1975), "Recommended Practices for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations", Institutions of Electrical and Electronics Engineers, 1975.
- * Canadian Standards Association, CAN-N289.3-M81, "Design Procedures for Seismic Qualification of Candu Nuclear Power Plants", September 1981.

1.3 Equipment Description

The OH-180 panels that will be qualified in the program are to be installed in various rooms in the Darlington NGS reactor auxiliary bay and emergency power supply building. The panels subject to environmental qualification are designed to hold up to five OH-180 programmable controller modules (crates), mounted on a vertical rack arrangement. Up to ten communications modules may be installed near the top of the cabinet. However, not all cabinets will have a full complement of controllers and communications units and various partially full cabinet

configurations will be installed in the plant. Cabinets may be installed singly, or in groups of two, three, four or six.

When these panels are installed in the field, they are securely anchored to a concrete plinth. Electrical cables enter through openings in the top of the cabinet. This mounting arrangement will be reproduced for the qualification tests.

1.4 Qualification Methodology

Qualification will be accomplished by a combination of dynamic shaker table testing, experimental modal test and finite element analysis.

Single panels will be qualified by table tests, using the Ontario Hydro Mechanical Research Department tri-axial shaker table. The shaker will produce motions that are as severe as the strongest floor motion predicted for the locations in the Darlington plant where this equipment will be installed.

We propose to test two panel configurations: a panel fully loaded with five programmable controller crates; and a panel with four crates plus a set of communications modules in the top space. For each configuration, the topmost programmable controller will be monitored for function during the shaker test. In the case where there are communications modules mounted in the panel, one of these will also be monitored. The components that are to be monitored are the ones which are expected to experience the most severe shaking during the tests or during an earthquake. The rationale for choosing these is based on our experience with similar electrical panels:

- The cabinet is a simple box structure. From our experience, we expect that the first and most significant mode of vibration of this structure will involve side-to-side swaying of the cabinet, at about 8 to 12 Hz.
- The structure of the rack-mount crates housing the OH-180 components is relatively flexible, so that adding more modules will increase the mass of the cabinet but only slightly increase the stiffness of the cabinet. Thus we expect the natural frequency of the cabinet to decrease as more modules are added.
- The floor response spectra show the highest response at frequencies below 10 Hz. Thus, the low frequency, fully loaded cabinets are expected to have a higher level of response than partly loaded cabinets.
- The level of response in the cabinet increases with elevation. Thus the strongest seismic response will occur in the top bay.

(2)

- When cabinets are mounted side-by-side and bolted together, the effect of the connection is to stiffen the combined structure. As well, small-scale slippage of the bolted connection increases damping effects. Thus, we believe that a single panel will experience more severe seismic shaking than a panel in any of the multi-panel line ups.

Since the shaker tests are designed to simulate "worst-case" configurations for both the enclosure structures and the OH-180 components and communications modules, then if they pass the qualification tests, it will be assumed that all other single panel configurations are also qualified.

The shaker table can only accommodate one panel at a time, so that longer line-up arrangements will be qualified through a finite element analysis. The basic strategy will be to demonstrate that the levels of response in the lineups is no greater than the response experienced during the single panel shaker tests. Mathematical models used in the analysis will be verified through modal testing of sample panels.

The qualification tests and analysis are intended to cover all OH-180 components manufactured to the same standard as the test samples and to cover all mounting configurations based on the five-high panel enclosure.

2.0 QUALIFICATION REQUIREMENTS

2.1 Seismic Conditions

The seismic Required Response Spectra (RRS) are depicted in the drawings NK38-60800-001 through -003. (Reproduced here as Figures 2 to 4.) The seismic Test Response Spectrum (TRS) must envelope the RRS over a frequency range of 1 to 33 Hz.

2.2 Acceptance Criteria

This equipment is required to remain functional during and after a DBE.

During the seismic shaker tests, the monitored programmable controller and communications module will run self-test programs (FUNC and GONOGO). The equipment will be considered to have passed the qualification tests if these programs run continuously and successfully during and after the shaking. This testing will be done under the supervision of the Electrical Research Department.

At least one of the cooling fans in the bottom of the cabinets must remain operational following the DBE.

Seismic qualification of multi-panel lineups will be shown using experimental modal tests and finite element analyses. Verification of finite element models is confirmed if at least first 2 vibration modes found by analysis match the vibration modes found by modal test. In addition, for each vibration mode of comparison, the natural frequency predicted by analysis must be within plus or minus 10 % of the actual frequency found by modal tests.

Panels installed in lineups will be considered qualified if the peak displacement of a panel in a lineup due to Required Response Spectra loading is less than the peak displacement of a single panel due to Test Response Spectra (ie. from shaker table tests) loading.

3.0 QUALIFICATION PROGRAM

3.1 Test Specimens

Darlington Engineering will supply two sample cabinets and eight OH-180 PC modules. Each of the cabinets will have four PC modules installed and provision in the top tier for mounting a communications unit. For one of the cabinets, a full set of cables will be connected to the topmost OH-180 module so that it can run its self-test program. Extra cables will be installed in the cabinet so that the total weight of the assembly matches that of a fully loaded panel. The second cabinet will be used to test the effect of inter-cabinet connections on the structural dynamic characteristics of the system. This cabinet will be loaded with OH-180 modules and the appropriate weight of cables.

Electrical Research Department will supply a sample communications unit and sufficient cabling and test hardware to enable one of the OH-180 modules and a communications unit to run self-test routines during the shaker test.

3.2 Shaker Table Tests

A single sample panel will be tested on the Ontario Hydro Mechanical Research Department tri-axial shaker table. This test rig is capable of providing pseudo-random accelerations of at least 1.5g to samples of equipment weighing up to 2000 kg.

A description of the test equipment, calibration procedures and test set-up is contained in Appendix A.

The panel will be mounted on the shaker table by an arrangement that simulates the field mounting conditions, as detailed in a memo (Fichman to Berezowsky) which is appended to this plan (Appendix B). Two sections of C180 X 18 steel channel will be

bolted to the shaker table by one-inch bolts (two per channel), while the cabinet will be bolted to the channels with 3/4 inch bolts.

During the shaker tests, the panel will be subjected to approximately 30 seconds of shaking. The amplitude and frequency content of the table motion will be tailored to envelope the RRS curves specified in Section 2.1 above. Tri-Axial accelerometer sets will be mounted near the base of the panels and near the top OH-180 module. Signals from these accelerometers will be processed by the shock spectrum analyzer to produce base motion and component motion response spectra. The latter spectra may serve as Required Response Spectra in the event that this equipment requires requalification at some future time.

During the shaker tests, one of the OH-180 controller systems (ie. one-half crate) and the communications module will run self test programs to verify that they remain fully functional. After the testing, the panels and internal structure will be inspected for signs of structural failure. If structural damage is found, it will be documented with sketches and written descriptions. Recommendations for avoiding these failures in production models will be made.

Although every effort will be made to provide very stiff mounting conditions, experience has shown that with tall equipment, where the centre of gravity lies above the plane of the horizontal actuators, some rocking of the table occurs. This rocking motion is not representative of in-plant seismic motion which would be more purely translational.

3.3 Modal Testing

The purpose of the modal testing is to verify finite element models used to extend the test-based qualification of single panels to the case of panels installed in lineups.

The first stage of modal testing will be carried out on a single panel, in a loaded configuration. These tests will determine the natural frequencies and mode shapes of the structure. The second phase of testing will involve two panels, mounted side by side and connected according to design specifications. These tests will determine the change in stiffness and structural damping.

The mounting for each panel will be patterned on the field mounting arrangement. The bottom of each panel will be anchored

by four three-quarter inch bolts to a length of steel channel. The steel channel will be welded to a four-inch steel plate which is bolted to a heavily reinforced concrete floor.

Dynamic loading for the modal tests will be provided by an hydraulic shaker attached near the top of the panel. The dynamic load will be sinusoidal and would be swept from 5 Hz to 50 Hz to 5 Hz.

Dynamic load and response acceleration data (tri-axial) will be collected for selected points on the panel(s). The data will be reduced and analyzed using a Gen-Rad structural analysis system, running SDRC "Modal Plus" software. This system will produce a description of the dynamic properties of the panel structure and will identify natural frequencies and mode shapes in the seismic frequency range.

3.4 Finite Element Analysis

Only single panels will be tested on the shaker table. Extrapolation of the shaker test data to lineups will be based on finite element analysis of the longer panel configurations.

Finite element models of all cabinet configurations described in section 1.3 will be developed using beam, plate and concentrated mass elements. A schematic sketch of a typical three dimensional model for a single panel is provided in Figure 1. The mass and stiffness contributions of cabinet doors will be considered. Dimensions, details and section properties will be taken from Ontario Hydro drawing no. ED 540072, Issue 2, "OH 180 Programmable Controller (EPS) Cabinet Weldment s/a 5 High Top Entry".

The single and two panel lineup models will be analyzed to determine their natural frequencies and mode shapes and verified by comparison with the results of the experimental modal analysis described above.

Response spectrum analysis of the panel lineup configurations will be used to evaluate the structural response of the multi-panel lineups and of a single panel. The analyses will only consider contributions from vibration modes with natural frequencies below 33 Hz. The contributions from each natural frequency considered will be combined using the square root of the sum of squares method. Lineups of panels will be considered to be qualified if it is demonstrated that the maximum deformation of any panel in any of the lineups due to RRS loading is no greater than the maximum deformation of a single panel due to TRS. The Required Response Spectra (RRS) curves for locations where OH-180 programmable controllers are installed are provided in Figures 2 to 4.

A structural damping ratio of 3 % of critical will be used, as recommended in Table 3 of CSA Std CAN-N289.3 (Item #4).

Transient analysis with acceleration time history loadings based on the floor response spectra will be used to simulate seismic motions at locations inside the panels. These motions will be used to compute response spectra for the locations where the OH-180 modules and communications units are mounted. Response spectra computed for locations inside the panels will be compared for single panel and multi-panel configurations.

3.5 Computer Programs

The MSC/NASTRAN system of programs will be used for the finite element analysis. These programs are widely used and accepted in the structural engineering community for structural dynamic analysis, including seismic qualification. Facilities for performing response spectrum analysis, time history transient analysis and response spectrum synthesis are included in the system. The analysts at Ontario Hydro Research Division have had over ten years experience in the use of these programs.

Transient analysis to produce secondary (on-panel) response spectra requires the generation of acceleration time histories that are "spectrum compatible" in the sense that they have amplitude and frequency content appropriate to the floor response spectrum. THIST, a special computer program has been written at Ontario Hydro Research Division to generate these time histories. This program is based on a method by Levy and Wilkinson (Nuclear Engineering and Design 38, 1976, pp 241-251). The program has been validated by demonstrating that the time histories it generates, when processed through MSC/NASTRAN, result in the desired spectrum.

Computerized reduction of modal testing data will be based on the "Modal Plus" software, supplied by Structural Dynamics Research Corporation. This package is widely used in the manufacturing and power generation industries.

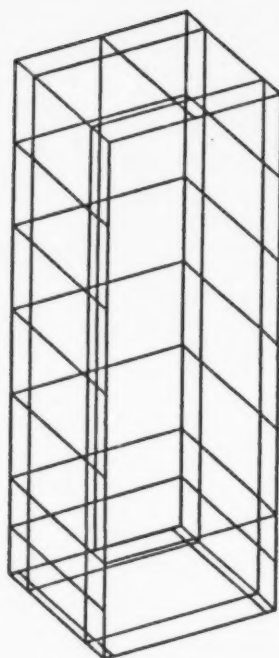


FIGURE 1

Typical Finite Element Model of an
OH 180 Programmable Controller

FLOOR RESPONSE SPECTRA

Project DARTINGTON GEA.

Structure POL ON 180

PROGRAMMABLE CONTROLLER

Grid ENVELOPE # EL.

E/Q Level DEF

Direction NORTH-SOUTH

Node Points ENVELOPE #

NK 31-0000-0000 RAE

Date DEC 17 1988

* THESE SPECTRA ARE ENVELOPES

OF THE FOLLOWING FRSI

- EPS BLEG EL 101.000 NK 38-28350-008 RO
- CCA EL 103.500 NK 38-22650-002 RZ
- RAE EL 111.000 NK 38-21190-008 RZ
- EL 121.500 NK 38-21190-008 RZ

Figure 2

1%

3%

5%

FREQUENCY (Hz)

FLOOR RESPONSE SPECTRA

Project D-CLINGTON GE 'A'

Structure FOR CH 15

PROGRAMMER: E. CONTOLLE

Grid ENVELOPE* EI 60

E/Q Level DBE

Direction VERTICAL

Node Points ENVELOPE*

NK 38-0000 - 003 R 5.0

Date DEC 12 1955

Figure 3

* THESE SPECTRA ARE ENVELOPES

OF THE FOLLOWING FR'S:

- EPI. ENDS EL 101,000 NK 38-28350-003 R0

- CCA EL 105,500 NK 38-22650-003 R1

- RAE EL 111,000 NK 38-21350-003 R0

EL 107,500 NK 38-21350-004 R0

1.0

0.5

0.0

1.0

0.0

0.0

0.0

0.0

0.0

0.0

0.0

0.0

0.0

0.0

0.0

0.0

0.0

0.0

0.0

ACCELERATION (g)

FREQUENCY (Hz)

FLOOR RESPONSE SPECTRA

Project D.A. LINGTON GS 'A'

Structure... FOR OH180

PROGRAMMABLE CALCULATORS

Grid ENVELOPE* EL... 60

E/Q Level... DBE

Direction... EAST-WEST

Node Points... ENVELOPE*

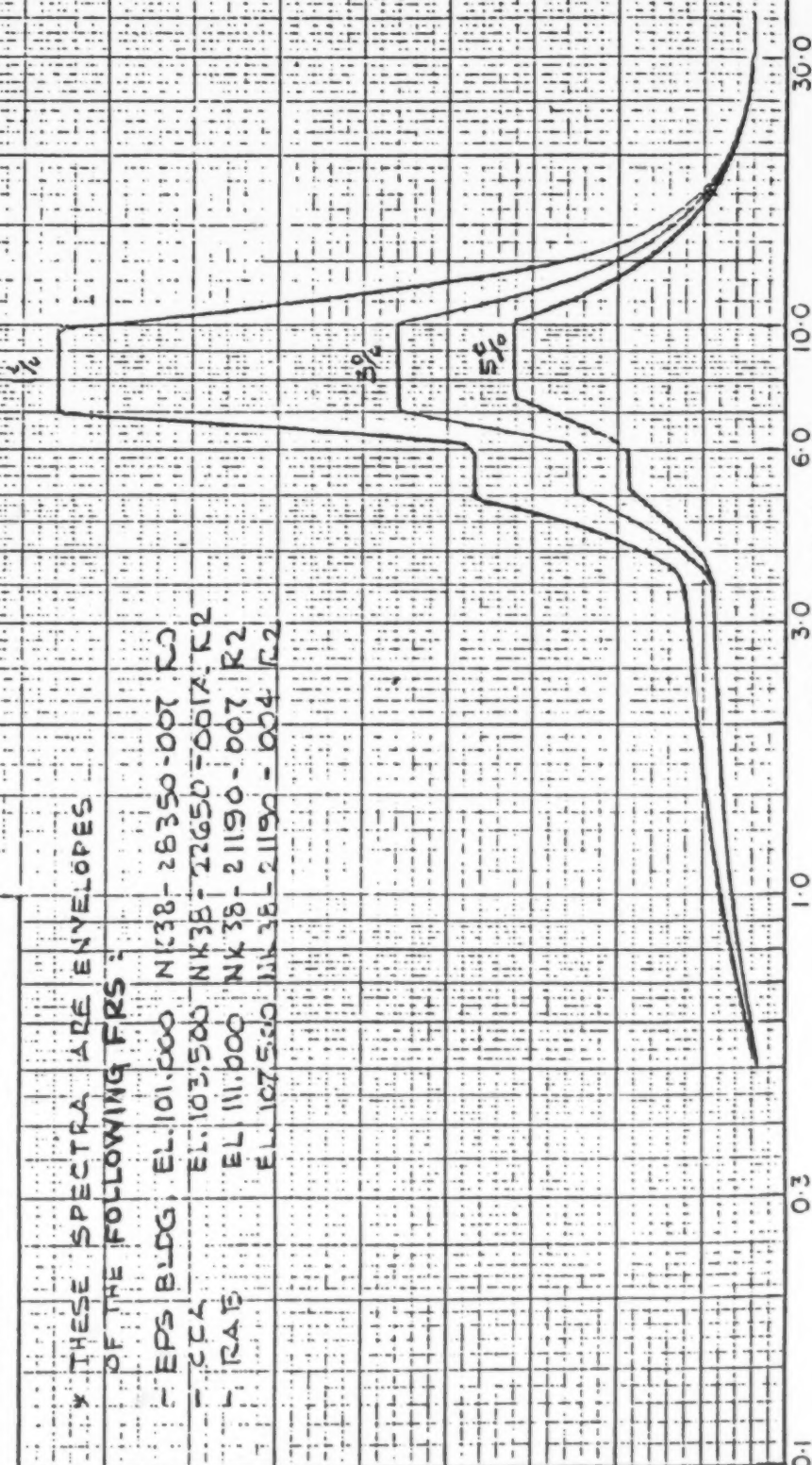
NK35 - 00500 - 001 R2 5.0

Date... DEC 17, 1983

Figure 4

* THESE SPECTRA ARE ENVELOPES
OF THE FOLLOWING FRs:

- EPS BLDG EL 101.000 NK38-26350-007 R2
- 2CA EL 103.500 NK38-22650-001A R2
- RAB EL 111.000 NK38-21190-007 R2
- EL 107.500 NK38-21190-004 R2



APPENDIX A

PROCEDURE FOR SHAKER TABLE TESTS OF A SINGLE
OH 180 PROGRAMMABLE CONTROLLER PANEL

1.0 SCOPE

This test procedure has been prepared for seismic qualification of OH 180 Programmable Controller panels by test in a single panel configuration. The tests are tri-axial with random inputs.

2.0 APPLICABLE QUALIFICATION STANDARDS, SPECIFICATIONS AND DOCUMENTS

IEEE 344 "IEEE Recommended Practices for Seismic Qualification of Class IE Equipment for Nuclear Power Generating Stations" 1975.

CSA Standard N289.4 "Testing Procedures for Seismic Qualification of CANDU Nuclear Power Plants" Draft 1977.

3.0 TECHNICAL ASPECTS

There are several methods which can be used to perform seismic qualification by testing. These methods include random excitation, sine sweep, steady sine, sine beat and other waveforms on a range of different shakers. In our test laboratory we have tried to limit the test methods to pseudo-random excitation on hydraulic tri-axial shakers.

3.1 TEST EQUIPMENT

The following test equipment is used to perform the seismic qualification. Each test set-up requires specific instrumentation.

3.1.1 SHAKER CONTROLS

S1. MTS 436.11 Control Units serial no. 721, 1315 and 257.

S2. MTS 406.11 Controllers Serial No. 1502, 2522, 2530, 2546 and 2228.

S3. Hydraulic pumps

S4. Ontario Hydro noise generators and filters No. 1, 2, 3 and 4.

S5. Ontario Hydro tri-axial shaker 2000kg capacity. Maximum displacement is 152mm in all directions and acceleration levels are 4g no load and 1.5g full load.

S6. Ontario Hydro tri-axial shaker 200kg capacity including MTS 244.21 Hydraulic Actuators Serial No. 229, 233 and 234. Maximum displacement is 409mm in X-direction, 472mm in Z-direction and 440mm in the vertical Y-direction.

S7. MTS Vibration Actuator

S8. Ontario Hydro Sine Beat on Random Circuit.

S9. Ontario Hydro Equilizer Circuit.

S10. MTS 410 Sweep Generator Serial No. 177

S11. MTS 410 Digital Function Generator Serial No. 949.

S12. MTS 421.21 Amplitude Controller Serial No. 151.

3.1.2 ANALYSIS EQUIPMENT

A1. Columbia Model 9000 amplifiers and matching Wilcoxon M-408 accelerometers.

Amplifier Serial No.	Accelerometer Serial No.
368 1632	S893
368 1633	S297
368 1634	S901
368 1635	S369
368 1636	S753
368 1637	S754
369 1638	S756
369 1640	S759
369 1641	S760
369 1642	S761
369 1643	S771

A2. SE tape recorder Model 7000A, Serial no. 547.

A3. Spectral Dynamics 13231 Shock Spectrum Analyser, Serial No. 27 c/w Spectral Dynamics 13191 Transient Memory, Serial No. 29.

A4. Ontario Hydro Interface Boards and Computer.

A5. Hewlett-Packard Model 7470S Digital Plotter, Serial No. 2210A-12990.

A6. Spectral Dynamics 50121L Tracking Filter, Serial No. 171 c/w Spectral Dynamics SD122L Tracking Filter, Serial No. 370.

A7. Ontario Hydro Transmissibility Circuit includes RMS to DC converters and divider.

A8. Watanabe WX4400 X-Y Recorder, Serial No. 83010070.

A9. Nicolet Scientific Corp, Model 660A Dual Channel FFT Analyzer, Serial No. 9866226.

A10. Honeywell 1858 Oscillograph, Serial No. 2649JF78.

A11. Tecktronix 5113 Dual Beam Storage Oscilloscope, KS3681.

A12. Data Precision 2440 Digital Voltmeter, Serial No. 5733.

A13. Data Precision 248 Digital Voltmeter, Serial No. 8583.

A14. SAN-EI 6M61 Strain Amplifier Serial No. 1120439.

A15. Hewlett-Packard 7046A X-Y1-Y2 Recorder Serial No. 1914A05842.

A16. PCB GK291B50 Instrumented Hammer.

A17. Matrix Chatter Monitors No. 1, 2 and 3.

A18. Hewlett-Packard 895A Regulated Power Supply Serial No. 1835A01746.

3.1.3 ENVIRONMENTAL CONDITIONING EQUIPMENT

E1. Digitron 2210 Temperature Scanner.

E2. Themotron SMX 35 5-5 Environmental Chamber 1 cubic meter capacity, -70 to +177°C, wet-bulb and dry-bulb controller.

E3. Thermotron WP2670-THCM4-25-25-RR Walk-in Environmental Chamber Serial No. 11407, 98 cubic meter capacity, -60 to +100°C, wet-bulb and dry-bulb controller.

E4. Despatch Industries PWC-2-91 Walk-in Oven 2.6 cubic meter capacity, +30 to +260°C, dry-bulb controller.

E5. Fisher Scientific

3.1.4 CALIBRATION EQUIPMENT

C1. Bruel and Kjaer Type 3506, Serial No. 877022 Accelerometer Calibration Set which includes Type 2626, Serial No. 842947 and Type 82055, Serial No. 858627 traceable to NBS.

C2. General Radio 1557-A Vibration Calibrator, Serial No. 2379.

C3. Fluke 8940A Multimeter, Serial No. traceable to NBS.

C4. Hewlett-Packard 5335A Universal Frequency Counter Serial No. 2232A03712 traceable to NBS.

C5. Anatek 25-22S Regulated Power Supply Serial No. 0519.

C6. Lambda LPT-7202-FM Regulated Power Supply Triple Output.

C7. Wavetek 182A 4MHz Function Generator Serial No. D7110651.

3.2 TEST SET-UPS

3.2.1 RESPONSE SPECTRUM METHOD

The response spectrum method uses the set-up shown in Figure 1. The components are described as follows:

1. Three hydraulic actuators (S5) have been mounted such that each actuator is nominally 90 degrees from each other. These actuators provide independent motion in three directions.

2. Since the hydraulic actuators have ball joints both ends a

mechanical restraint system is required.

3. The table (S5) is a flat surface to which equipment can be bolted. A test fixture is often required to adapt the equipment to the table. Equipment may be welded to the fixture.

4. Three accelerometers (A1) are glued to the table or test fixture to measure the acceleration. The location is chosen to reflect where the required response spectrum applies. The accelerometers are 90 degrees to each other and each is sensitive in only one axis. Their orientation with respect to the test equipment establishes the axes of vibration. We normally use X-Y&Z co-ordinates with Y being vertical.

5. Amplifiers (A1) are required to power the accelerometers and boost the voltage to a useable signal. Cables are used to join the accelerometer to the amplifier. Since we are using charge type accelerometers, the cable length has no effect on the calibration. Cables are taped down to prevent cable whip.

6. The FM tape recorder (A2) receives the amplifiers signal and stores the analog acceleration signal. Up to 14 channels can be simultaneously recorded. Channel 14 is reserved for recording a start signal which is used to time the inputs to the shock spectrum analyser. All three acceleration signals are recorded simultaneously.

7. A switch channels each signal through the shock spectrum analyser one signal at a time.

8. The shock spectrum analyser (A3) analyses the single recorded acceleration signal to give the test response spectrum. Each channel is separately analysed. A trigger signal from channel 14 starts the analyser at the proper time.

9. The computer (A4) collects the data from the shock spectrum analyser and the keyboard. The data is then put in the appropriate form to be used by the digital plotter.

10. The digital plotter (A5) plots the data in a form suitable for the report.

11. Three random generators (S4) generate a random signal which varies randomly in time, frequency and amplitude. Each generator must be powered up separately to achieve complete independence.

12. Three servo controllers (S2) receive the reference signal and close a servo loop between servo valves mounted on the actuator and a displacement transducer.

13. The pump controller (S1) starts and stops the hydraulic pumps (S3) and controls the pressure to the shaker.

3.2.1.1 CALIBRATION CONSIDERATIONS

From Figure 1 there is no electrical connection between the shaker control system and the analysis system except for the trigger signal. This signal is not part of the analysis. The computer only collects numbers from the shock spectrum analyser and feeds digital data to the plotter. Therefore, only the accelerometer amplifiers, tape recorder and shock spectrum analyser require calibration adjustments. The accelerometers, computer and digital plotter are not adjustable.

3.3 CALIBRATION

3.3.1 ACCELEROMETERS

Accelerometers and amplifiers are calibrated using the back-to-back calibration procedure. The reference accelerometer (C1) is mounted to

the vibration calibrator (C2) along with the Wilcoxon accelerometer (A1) see Figure 6. Using a 100 Hz sine wave vibration of approximately 1 g, the sensitivity of the Columbia amplifiers (A1) is set to give a known output. The outputs are measured using the Fluke multimeter (C3). By using the same voltmeter to measure the reference accelerometer as the unknown accelerometer, differences in voltmeters is no longer a consideration. Since the voltmeter measures the true RMS voltage the signals are also compared on the oscilloscope (A11). This ensures that the signals are equivalent. The sensitivity of each range is verified using the internal calibrate signal of the amplifier. Occasionally problems occur due to faulty cables or loose connections. This can be recognised during the test by a lost signal or peculiar results. To minimize the problem the micro dot connectors are tightened with pliers. The cables are also taped down to eliminate cable whip. The calibration is independent of the cable length.

3.3.2 TAPE RECORDER CALIBRATION

The tape recorder is calibrated using recommended manufacturer's instructions as follows:

1. The Fluke multimeter (C3) is connected to the tape recorder (A2) scope socket.

FM PLAY MODULE ZERO ADJUSTMENT

1. At the calibrator unit the following conditions are set:
 - a. EE/OSC switch is set to OSC.
 - b. Fo/F1 switch is set to Fo.
 - c. METER switches are set to DC and Hi.
 - d. SG/DC switch is set to DC.
 - e. 0 V/-V switch is set to 0 V.
 - f. Calibrator unit Play output switch is set to the appropriate channel to be calibrated.
 2. At the FM Play module adjust R60 (OUTPUT ZERO) to give $0.000\text{V} \pm 8\text{mV}$ on the multimeter.
 3. Ensure that the FM Play module output remains within $\pm 8\text{mV}$ of 0 volts for all speeds and with WB1 selected and de-selected.
 4. Record maximum deviation and whether or not adjustments were necessary.
 5. Repeat for each play module.
- #### FM PLAY MODULE GAIN ADJUSTMENT

1. At the calibrator set the Fo/F1 switch to F1. Leave the other switches as is.
2. At the FM Play module adjust R66 (OUTPUT GAIN) control for $-1.500\text{V} \pm 15\text{mV}$. Rotary switch is set to the appropriate channel.
3. Ensure that the output remains within $\pm 15\text{mV}$ of -1.500V for all speeds and with WB1 selected and de-selected.
4. Record the maximum deviation and whether or not an adjustment was necessary.

FM RECORD MODULE ZERO ADJUSTMENT

1. At the calibrator set EE/OSC switch to EE and 0V/-V switch to 0V. The other switches remain in the last set position.
2. The rotary switch is set to position 1 or to a channel with a play module. If no play module is present then each record module must be

placed in slot 1.

3. At each FM Record module remove and place in slot 1 (except channels 12,13&14), press and hold the CAL switch (SA) and the EE switch (SC) and adjust R22 (Z) for $0.000V \pm 15mV$. Ensure that the output remaining within this limit for all speeds and with WB1 selected and de-selected.

4. Record the maximum deviation for each channel and indicate if an adjustment was necessary.

FM RECORD MODULE GAIN ADJUSTMENT

1. At the calibrator set the $0V/-V$ switch to $-V$. Leave the other switches unchanged.

2. Set the rotary switch to channel 1 for channels 1 to 11 or the appropriate position for the other channels.

3. It is necessary to put each record module in slot 1 for channels 1 through 11.

4. At the calibrator press and hold the SET-V switch and adjust the potentiometer to give the desired input voltage. On the Fluke multimeter.

5. At the Record module being adjusted press and hold the CAL (SA) and adjust R8 for a reading of $-1.500V \pm 15mV$.

6. It may be necessary to adjust the coarse gain switch on the circuit board to achieve a setting. Positions of switch (SB) are as follows: A = 5 to 10V, B = 2 to 5V, D = 1 to 2V and E = 0.5 to 1V.

7. Ensure all speeds and WB1 selected are within the tolerance above. Record the maximum deviation and indicate if adjustments were necessary.

3.3.3 CALIBRATION OF SHOCK SPECTRUM ANALYSER

To calibrate the shock spectrum analyser (A3) and verify the computer (A4) and digital plotter (A5) the following procedure is used:

1. Input range attenuator set for 0 dB.

2. Check TP1 for 31.62 mV DC using the Multimeter (4C).

3. Press CAL and load the internal calibration signal.

4. Analyse the MAXIMAX shock spectrum at $Q = 100$ and plot data.

5. Check plotted data against desired display.

6. Analyse a grounded input and verify against the desired display.

7. Date the plots and install in QA manual.

4.0 EQUIPMENT SET-UP

The equipment will be mounted as shown in Figure 2. Welding will be reduced to remain conservative. The required response spectrums are shown. These will be combined into the worst case horizontal and worst case vertical conditions.

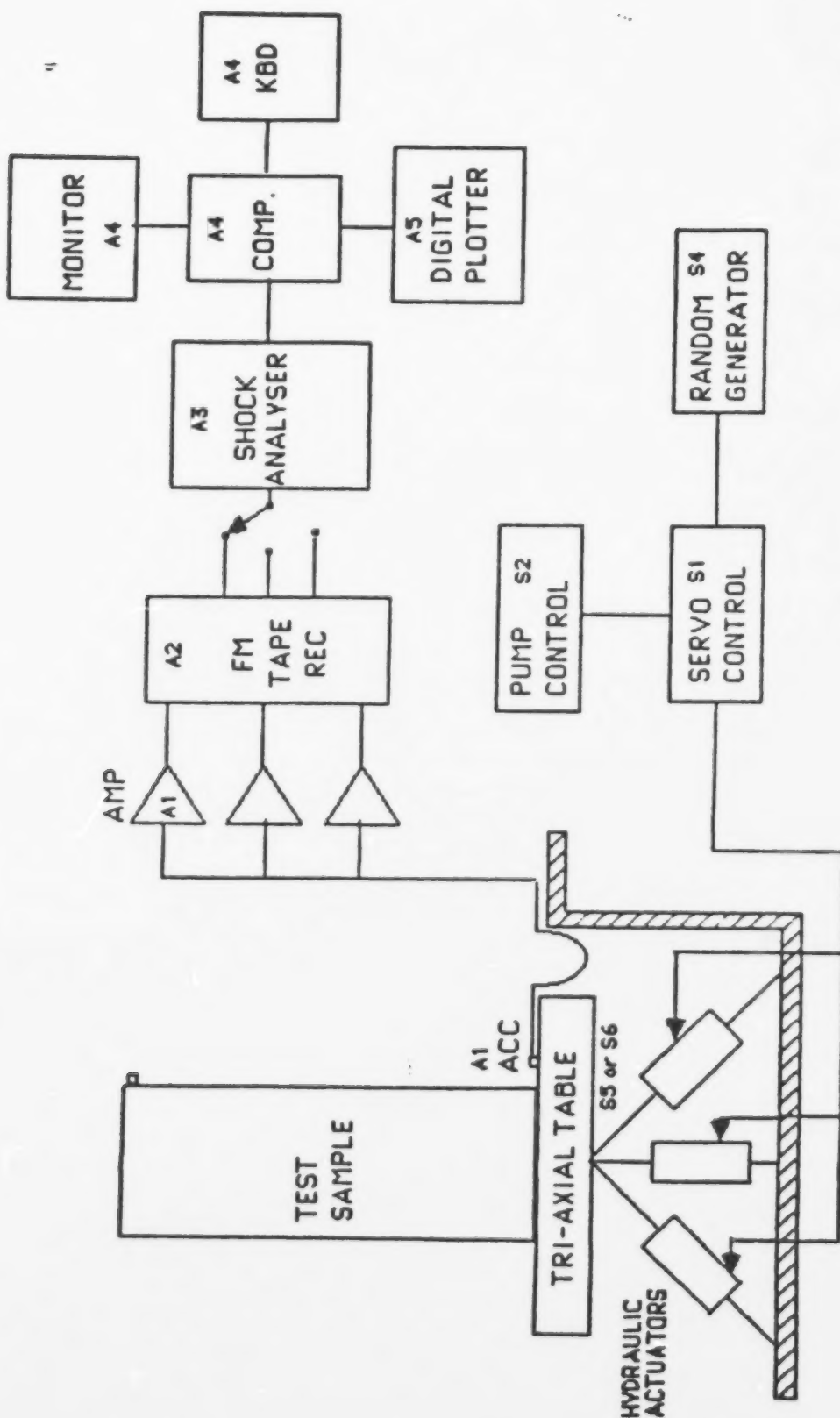


FIGURE 1

Block diagram for Seismic Testing using Random Vibration and Shock Spectrum Analyser to obtain Test Response Spectrums

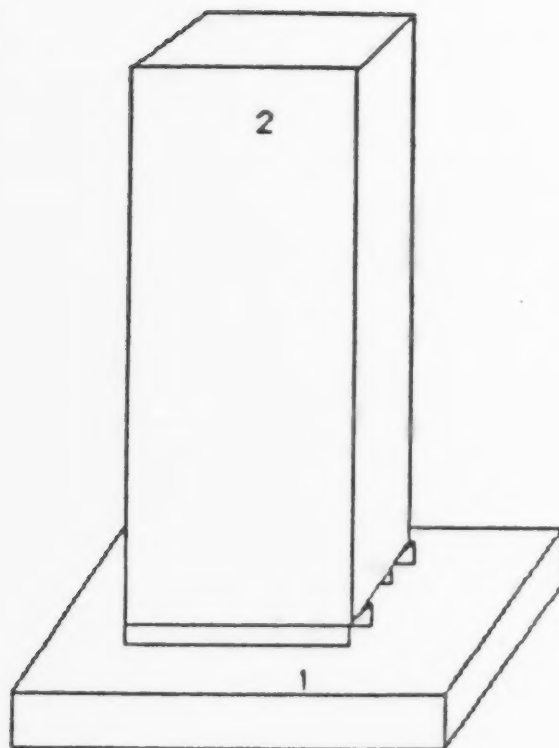


Figure 2.

Welding will be minimized to be conservative.
Typical Arrangement for Mounting Panels to the
Tri-axial Shaker Table. Accelerometers will be located
at positions 1 and 2. Location of point 2 is to be
selected as the worst case by modal analysis.

TABLE 1
INSTALLATION BOLT TORQUES

<u>Size</u>	<u>Torque</u>	<u>Nm</u>
#10	18 in-lb	2.03
#12	28 in-lb	3.16
1/4"	45 in-lb	5.09
5/16"	85 in-lb	9.61
3/8"	150 in-lb	17.0
7/16"	250 in-lb	28.3
1/2"	33 ft-lb	44.7
9/16"	45 ft-lb	61.0
5/8"	63 ft-lb	85.4
3/4"	110 ft-lb	147.0
7/8"	180 ft-lb	244.0
1"	260 ft-lb	353.0

Note: Torque based on 45% of F_{ult} of SAE Grade 1 bolts

APPENDIX B

memo to:

from:

I. B. BEREZOWSKY H 16

T. FICHMAN - DARLINGTON CIVIL

SENIOR DESIGN ENGINEER ELECTRICAL

H 16- C 21

subject:

date

OH 180 PROGRAMMABLE CONTROLLER - CHANNELS FOR INSTALLATION OF CABINETS

MAY 2, 1985

message:

file

21390
WK38 { 22690 T.

THE CHANNELS TO BE USED FOR THE INSTALLATION OF CABINETS SHALL BE
C 180 X 18 X 700 mm LG. WITH 4-22 ϕ HOLES PER CHANNEL.

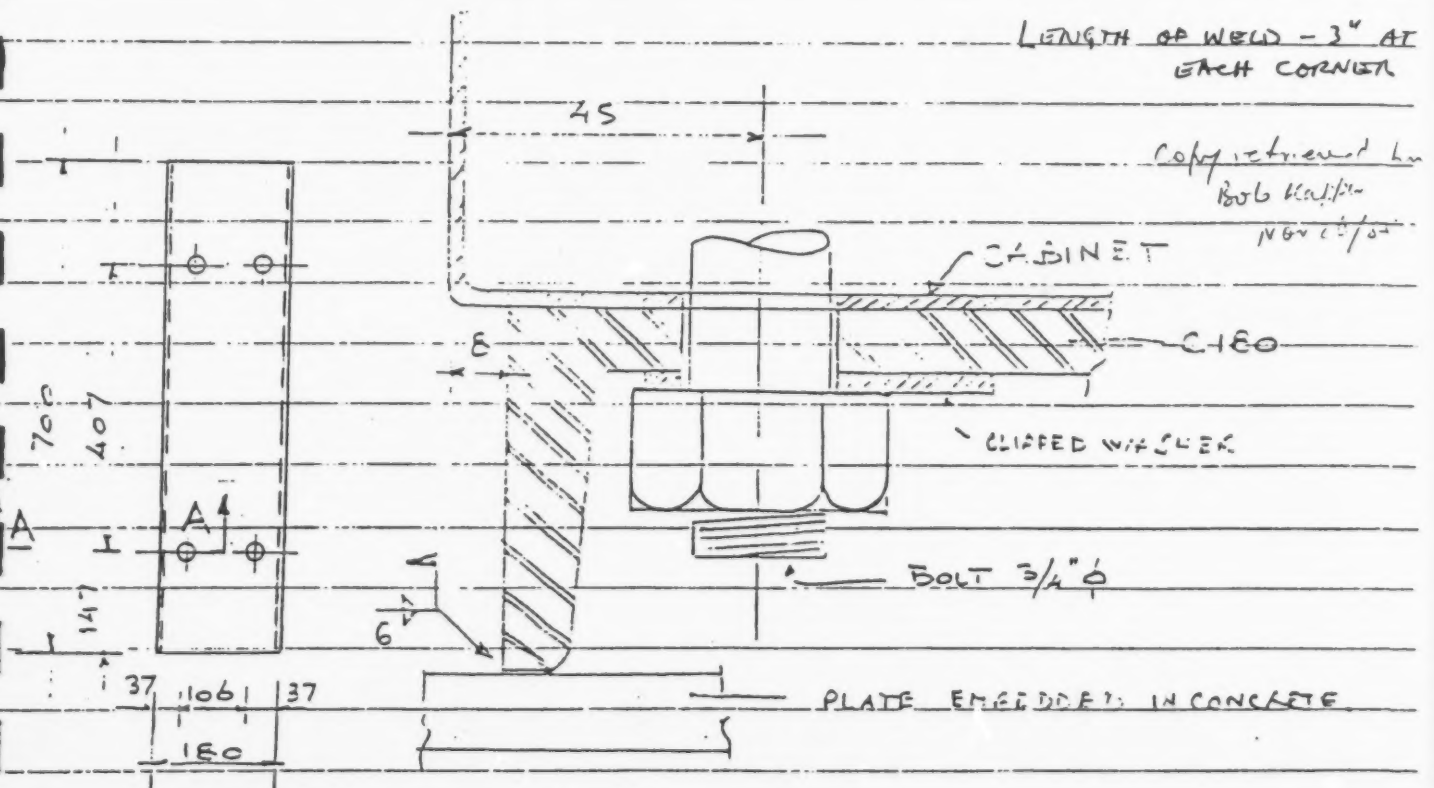
THE MATERIAL IS G40.21M - 300 W. CLIPPED WASHERS ARE REQUIRED.

THE CHANNELS WILL BE WELDED TO THE EMBEDDED PLATES ON TOP OF

THE FLOOR THE QUANTITY IS: 26 FOR ROOM SM 105

19 FOR ROOM 252

TOTAL: 45 CHANNELS - 700 mm LG



SECTION A-A

TYPICAL CHANNEL
(PLAN)

C.C. R. KAPPA
J.C. LER

16TH FL
16TH FL

(- 23 -)

- 87 -

T. FICHMAN

DESIGN ENGINEER SPECIALIST

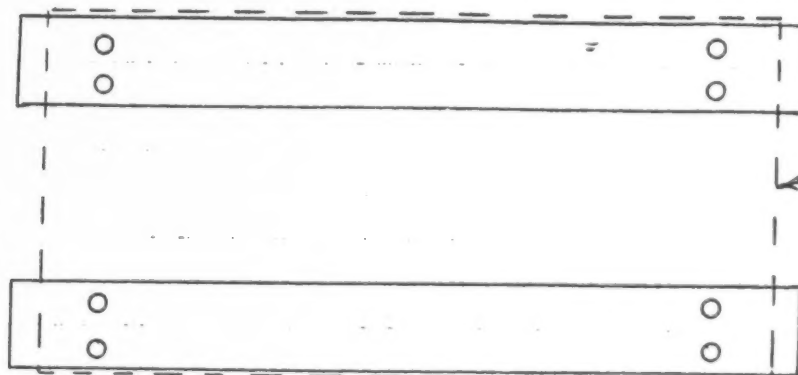
86-277

INSTALLATION

NOTES

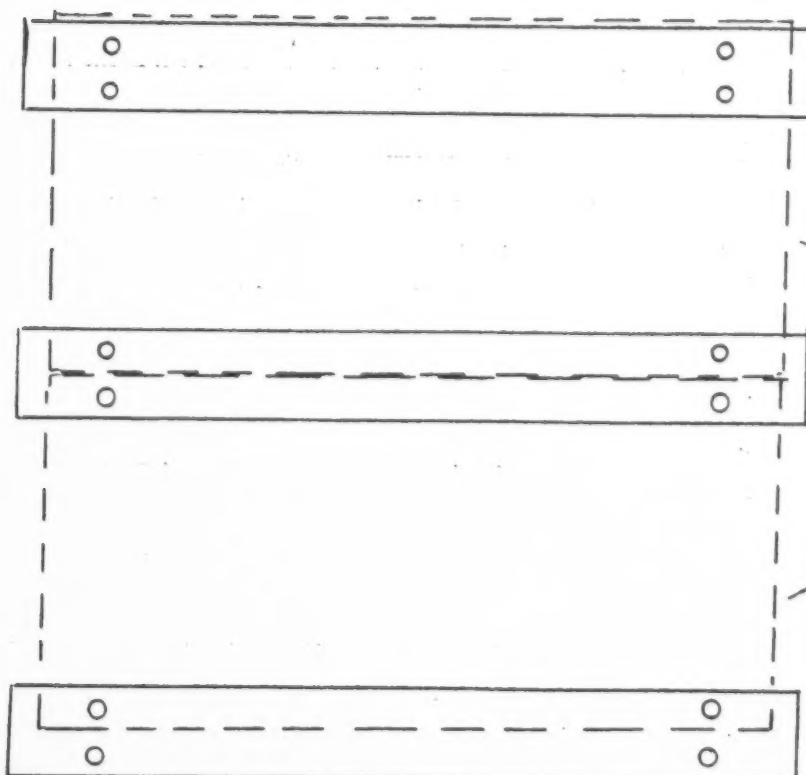
SINGLE CABINET

NOT TO SCALE



EXPECTED
LOCATION OF
CABINET

TWO CABINETS WITH PROVISION
FOR THIRD FUTURE CABINET



EXPECTED
LOCATIONS OF
CABINETS

FUTURE
CABINET